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DIRECTIONAL UNDERWATER NOISE ESTIMATES - THE DUNES MODEL

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TECHNICAL NOTE
WSRL-TN-34/89

DIRECTIONAL UNDERWATER NOISE ESTIMATES - THE DUNES MODEL

R.W. Bannister, D.J. Kewley and A.S. Burgess

SUMMARY (U)

The modelling of the directionality of underwater noise due to wind-generated noise sources and shipping is presented. The formulations are incorporated in the Directional Underwater Noise Estimates - DUNES model. It provides estimates of omnidirectional, vertical, horizontal and three dimensional directional noise versus frequency. The model includes features hitherto unknown in models of this type ie high latitude and coastal slope enhanced wind noise. The model emphasises the calculation of noise due to the natural environment and therefore shipping contributions have to be entered explicitly, unlike some other models which incorporate extensive shipping databases. Long range wind noise is considered to be described by storms over a finite area and bearing or along continental shelves. Shipping is described by individual ships or shipping lanes over continental shelves or deep ocean. The model has been used on a range of computers such as the IBM PC, VAX 11/750 and IBM 3033. Examples of use for Version 2.3 are provided.

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1. INTRODUCTION

The waters surrounding Australia and New Zealand are relatively free from ship traffic. As a result, natural noise sources assume significance in the frequency band 20 to 200 Hz. This is in contrast to many areas in the northern hemisphere where shipping noise dominates this part of the spectrum. In spite of these differences, however, there are many features of the measured three-dimensional ambient noise field which appear similar in both hemispheres. For example there is a broad spectral peak in the vicinity of 50 Hz(ref.1) and the maximum of omnidirectional noise occurs around SOFAR channel depths(ref.2,3). In the vertical plane, there is a peak in energy received at angles near to the horizontal(ref.2,3) and horizontal noise directionality shows considerable azimuthal dependence.

In the northern hemisphere, these attributes have been shown to be dominated by the presence of shipping, often enhanced by low-loss transmission paths which occur when vessels are at high latitudes or over sloping bathymetry(ref.4). Similar characteristics which are measured in southern oceans(ref.3,5,6) do not easily fit the same explanation. There are fewer ships overall, negligible numbers suitably placed above bathymetric slopes and practically none at all at high latitude.

The apparent inconsistency between interpretation of the broad features of northern and southern hemisphere noise data has challenged us to attempt to further understand the role and characteristics of wind generated ambient noise. Since the difficulties appear to be fundamental it was decided to construct an ambient noise model which emphasises in simple form the various physical processes in operation. The wind generated noise source is regarded as being distributed over the ocean surface with simple latitude and seasonal variation. The model simulates the acoustic 'view' at a receiving point and traces various transmission processes back to an interaction with the sea surface source. Each transmission family has characteristic physical properties and can be associated with a specific set of vertical and horizontal angles. This model, known as DUNES (Directional Underwater Noise Estimates or more colloquially Down Under Noise Estimates) has been benchmarked against a set of vertical noise measurements from southern ocean environments.

The model has been, and is continuing to be modified in response to revised interpretations of noise mechanisms and paths. Consequently this report attempts to describe Version 2.3 which, as seen in the text, can be further improved by removing assumptions and adding more features. Therefore by the time this Technical Note appears, new research may require further changes.

This report is organised into two main sections. Part one describes (and derives where necessary) the algorithms used in the noise model. Part two is a users guide for the software implementation of the model and describes how to establish and arrange parameters. Additional notes and Worksheet are given in the Appendices.

2. THE DUNES MODEL ALGORITHMS

2.1 Overview

The DUNES model estimates the noise arriving at a receiver as the sum of contributions associated with different transmission types as indicated in figure 1. Each transmission type can be assigned a vertical angle interval at the receiver as indicated in figure 2 (derived from reference 7). The angle defining the change from the direct to BB components is represented in figure 2 by the critical angle. Rays arriving at angles greater than

this critical angle undergo much larger losses upon reflection at the sea bottom than for smaller angles. Its value can be found from the angular dependence of bottom loss, see Appendix III. The DUNES model also allocates horizontal sections for the various components. It can be assumed that local (or direct), RSR and BB components arrive uniformly from all horizontal directions (unless major topographic blockage occurs within 100 km of the receiver). The RR component however, arises from distant noise sources either over seamounts, over continental slopes or from high latitude and the azimuth can be determined from geometry.

The following sections will develop and discuss the algorithms used in DUNES to predict the noise components illustrated in figures 1 and 2. The values of the vertical angle assignments shown in figure 2 correspond to the case of deep water with a depth excess in the sound speed profile. For cases of bottom limited or no deep sound channel propagation these assignments will change and whole intervals can be eliminated. The values are discussed in Sections 2 and 3.

2.2 Source level of wind noise

2.2.1 Source spectrum

Wind generated noise arises from a distributed source near to the ocean surface. The source level is described quantitatively in decibels re 1 $\mu Pa^2/Hz/m^2$ of surface area at one metre. This has been estimated recently by Burgess and Kewley(ref.5) and by Wilson(ref.8). Wilson's source levels are derived from omnidirectional noise measurements selected from locations where direct path conditions dominate. Burgess and Kewley, have derived an alternative technique to directly measure the surface source level using upward and downward steered beams from a vertical array. This method specifically accounts for the effects of bottom loss on the measured vertical noise levels. The Burgess and Kewley approach estimates effective downwards monopole levels ie the product of the source level and its downwards directivity function. This is important in the present study, since surface dipole effects are explicitly included in the propagation loss models and so effective monopole source levels must be used.

The analytic form of source level used in the model is obtained from an updated version of Burgess and Kewley's curves(ref.9) which incorporated additional data obtained from the Indian Ocean(ref.10). The expression for the source level at steep angles used here is

$$S(\text{dB re } 1\ \mu Pa^2/Hz - m^2 \text{ at } 1\ m)$$

$$= S_1 - 2.8(S_2 - S_1) + 1.66(S_2 - S_1)\log f \qquad (1)$$

where $S_1 = 37 + 12 \log W$

$S_2 = 25 + 20 \log W$

f = frequency (Hz)

w = wind speed (kn)

In addition, values of S below 50 Hz and between 200 Hz and 1 kHz are held constant. The resulting curves are shown in figure 3(a) superimposed on the source level measurements of Burgess and Kewley(ref.9). (It is shown in Appendix V that the error in converting from units of dB re 1 $\mu Pa^2/(Hz - sr)$ to dB re 1 $\mu Pa^2/(Hz - m^2)$ at 1 m is

less than 0.3 dB so both sets of units are virtually interchangeable). At higher frequencies the values above 1 kHz are reduced by 11 dB/decade. This reduction leads to the observed 17 dB/decade falloff of omnidirectional noise level. At very low frequencies the data summary of Kibblewhite and Ewans(ref.11) was used to estimate an additional noise term

$$S_{VLF} = 16.6 - 50 \log(f/50) + 10 \log(W/10)$$

to be combined with S in equation (1) by power summation to give values of source level down to 10 Hz. It is interesting to note a major difference between equation (1) and the results quoted by Wilson(ref.8). Wilson's source level curves have a uniform wind speed dependence (45 log (wind speed)) over the whole frequency band (10 to 1000 Hz). However, the expression derived from Burgess and Kewley, has a 12 log (wind speed) variation below 50 Hz and 20 log (wind speed) variation above 200 Hz. The differences between these two estimates can be resolved if the effects of source depth are included. This point is discussed in the next section.

2.2.2 Wind noise source depth

The source level estimate made by Burgess and Kewley is based on a measurement using nearly vertical beams. Thus, horizontally arriving energy is specifically eliminated and results are free from major surface dipole loss effects. The Burgess and Kewley source level is therefore an effective monopole value and so surface dipole effects at low angles must be included in the long range transmission loss estimate used to assess received noise. Indeed, it will be shown later that for this reason the received level is dependent upon the monopole source depth. Consequently, it is necessary to estimate the source depth of wind generated noise.

The most desirable approach to this problem would be to start with an understanding of the physical mechanism of wind generated noise and from this to estimate an effective source depth. Unfortunately the mechanisms are not clearly established. This has left us with the need to find an empirical solution by comparing DUNES predictions with measured data, particularly at frequencies less than 100 Hz. This procedure has indicated clearly that the source depth must be both wind speed and frequency dependent. Effective source depths inferred in this manner are shown in figure 3(b).

Some rationale can be applied to these results in physical terms. The source model implies a process which extends deeper with increasing wind speed. It is reasonable to expect both turbulence and entrained bubble activity to extend to deeper depths under conditions of high surface wave activity than under calm conditions. A possible mechanism has been suggested by Carey and Browning(ref.12). Turbulent pressure fluctuations which are coupled to the water from air turbulence, may oscillate entrained bubbles. The bubbles then become sound radiators. Since bubble clouds are observed in the ocean(ref.13) at depths which depend on wind speed, this may well be a relevant mechanism. The source consists of a series of incoherent line radiators oriented vertically whose length changes with time but varies consistently with wind speed. The time variability is reduced by geographic averaging over a large surface area of the ocean.

Using the empirical relationship between significant wave height and wind speed as(ref.14)

$$W_h \approx 0.00133\ W_s^{2.5}$$

where W_h = significant wave height in metres
W_s = wind speed in knots,

a source depth (h_s) of five times the significant wave height is found to produce DUNES predictions consistent with measurement. Thus

$$h_s = 0.00665\ W_s^{2.5} \qquad (1(a))$$

This expression, perhaps coincidentally, also fits the spread of data in reference 13 of bubble depth versus wind speed up to 20 kn.

However, there is an additional factor which is related to the surface interference effect. It can be shown that the first interference maximum as a function of depth occurs at a source depth of $h_s = 0.25/\sin\Theta_o$ (wave lengths) (where Θ_o is the surface grazing angle). It is assumed that once the source depth has reached this limit, further depth increase will not significantly affect the radiated energy. Thus the algorithm used in the DUNES model is for the source depth to vary as in equation (1(a)) with a lower limit of $\lambda/4$. Figure 3(b) shows this graphically.

The assumption of $\lambda/4$ as the limit for source depth fulfills the authors expectation that the source of noise will be at shallower depths as the frequency increases. However at the higher frequencies considered in the model (up to 10 kHz) this depth is comparable to the variation of the sea surface away from the horizontal. The assumption of a pure dipole surface interference effect with a flat surface will therefore be unlikely to be valid for most wind speeds. However, as will be seen later, the dipole does not contribute to the longer range noise at these frequencies and an effective monopole source dominates most of the noise levels at low receive angles (BB and RSR). Thus the $\lambda/4$ is shown to be not a critical factor at the higher frequencies. As stated before, physical understanding of the sources of noise will eventually tell us whether these assumptions are valid. Thus a plane of sources at $\lambda/4$ may be too simple an approximation to represent a volume of sources over a larger depth range.

2.3 The refracted - refracted (RR) components

The existence and importance of the RR components has been known for some time and stressed in recent papers(ref.2,4,15). The RR component requires horizontal gradients in either bathymetry or sound speed to carry energy from surface sources to the deep RR duct. These conditions are met when noise sources (either shipping(ref.2) or wind(ref.16) are over bathymetric slopes or at high latitudes where the SOFAR channel axis approaches the surface(ref.15)).

Situations of this sort are conveniently approached by integrating the noise contribution of a rectangular distributed source element over appropriate range intervals. As discussed in reference 16 the cylindrical transmission loss (L_{RR}) of the form

$$L_{RR} = 70 + 10 \log R + \alpha R \tag{2}$$

where R = Range (km)
α = Water column attenuation appropriate to the sound source (dB/km)

can be assumed.

References 16 and 17 show that the received noise level (I_{RR}) due to this component is estimated by

$$I_{RR} = S_K + 10 \log W - 70 + 3 + K - \alpha R\sqrt{x_1^2/4R^2 + 1} \tag{3}$$

where $K = 10 \log[\ln(x_1/R + \sqrt{x_1^2/R^2 + 1})]$
x_1 = half the length of the symmetrical noise lane (km)
R = the perpendicular range of the noise lane from the receiver (km)
W = the width of the noise lane (km)
S_K = the source level per kilometres^2
$= S + 60$

Note that the noise lanes used in DUNES are assumed to be symmetrical about the point of closest approach and therefore equation (3) differs from equation (A4) of reference 16 by 3 dB.

Equation (3) can be applied to distributed wind noise sources at high latitude or over bathymetric slopes as discussed in reference 16. The same equation applies to shipping in similar situations if the source level of shipping is assumed to be uniformly distributed over a ship lane - this is discussed in Section 2.9.2 The RR contribution is received over vertical angles of $\pm\theta_o = \cos^{-1}(C_o/C_s)$ where C_o, C_s are sound speeds at the receiver and surface. DUNES does not allow an RR contribution unless $C_s > C_o$ and $C_B > C_o$.

High-latitude, wind-generated noise has a seasonal and latitude dependence as discussed in reference 16. The frequency spectrum of this component (figure 11) is such as to confine its significance to the total noise to frequencies below 200 Hz. This effect is due to the water column attenuation of the high frequencies over the very long ranges to the high latitude sources. Note that the high latitude wind calculations in DUNES use the source levels presented in reference 16. These are similar to equation (1) at 10 kn but have greater values at higher wind speeds. These values were used so that DUNES would be consistent with the earlier publication. To take into account surface decoupling, an f^{-1} loss is applied to I_{RR} below 40 Hz. As discussed in later sections the loss term

depends upon source directionality and depth, giving rise to an increasing loss for decreasing frequency. The loss term used is a first approximation.

The additional contribution from sources over bathymetric slopes extends to higher frequencies (figure 11). This is a consequence of the shorter average distance between source and receiver producing less high frequency attenuation in the water column. Thus, the slope enhanced component is likely to dominate in the RR angles above 200 Hz. This component is, of course, very dependent on the location of the receiver relative to bathymetric features.

2.4 The RSR component - transmission loss

2.4.1 General law

The RSR component does not have any bottom interactions so it can be reasonably expected to have a cylindrical spreading loss (L_{RSR}) plus water column attenuation.

viz

$$L_{RSR} = 70 + 10 \log R + \alpha R \tag{4}$$

where the value of α is appropriate to the receiver location. The constant 70 is the generally accepted empirical constant obtained for RSR paths to deep sources and receivers. In the present case, however, the effective source depth is shallow and surface dipole effects need to be included.

This is done by integrating the surface dipole response over the angle limits relevant to RSR. These are between zero and $\theta_1 = \cos^{-1} (C_o/C_B)$. The latter angle describes the launch angle of a ray at the receiver depth which grazes the ocean bottom. C_B is the water speed of sound at the bottom. The dipole intensity (I_z) as a function of surface angle θ and source depth z (wavelengths) is

$$I_z = 4|P|^2 \sin^2 \chi$$

where $|P|^2$ = monopole power level

and χ = phase difference between the direct path ray and surface reflected path ray

Assuming isospeed conditions at the source depth:

$$\chi = 2\pi z \sin \theta$$

$$\simeq 2\pi z \theta \quad (\text{if } \sin \theta \simeq \theta)$$

Thus the integrated surface dipole loss is

$$I_{DIPOLE} = 4 \int_{0}^{\Theta_1} \sin^2(2\pi\, z\, \Theta)\, d\Theta$$

$$= 2\Theta_1 - \sin 4\pi\, z\, \Theta_1/(2\pi\, z)$$

When this is compared to the equivalent monopole energy loss over the same angle limits (namely Θ_1) for which the simple loss law (equation (4)) applies, then the resulting decoupling factor relative to equation (4) conditions is given by

$$D_{RSR} = I_{DIPOLE}/I_{MONOPOLE}$$

$$= (2\Theta_1 - \sin 4\pi\, z\, \Theta_1/(2\pi\, z))/\theta_1 \qquad (5)$$

$$= 2 - \sin(4\pi\, z\, \Theta_1)/(2\pi\, z\, \Theta_1)$$

This is graphed in figures 4 and 5, from which the following points can be made.

2.4.2 The effect of source depth

The process is very dependent upon source depth. If the source depth of wind generated noise is assumed constant (in metres) then there is a 6 dB/octave low-frequency roll-off. For example, assuming a 7.5 m depth this gives typical losses of -2 dB at 200 Hz; -8 dB at 100 Hz, -14 dB at 50 Hz and -20 dB at 25 Hz (figure 5).

Unfortunately, the experimental sites used to benchmark the model do not exhibit clear evidence of the RSR component. It has thus not been possible to check the above formulation directly. At present the assumed source depth is found by making it wind speed and frequency dependent as discussed in Section 2.2.2 and figure 3(b).

2.4.3 The effect of the dipole null

As the surface angle approaches zero, the response of the surface dipole becomes very low. When the local sound speed profile is such that RSR rays are confined to near zero angles, the contribution is significantly reduced. This is clear in figures 4 and 5. The dipole null, however, is not likely to be perfect and some lower limit to the null should be postulated on physical grounds. Null-filling will be caused by scattering and the rays responding to the detailed shape of the near-surface sound speed profile. In the absence of any properly developed theory an arbitrary lower limit of -10 dB is set by adding 0.1 to the decoupling factor. This decision is not robust since the magnitude and frequency content of the RSR component is sensitive to this procedure. Relevant data are not available to check results.

2.4.4 The attenuation coefficient

The value of α in equations (2) and (4) represents all relevant range dependent losses in excess of cylindrical spreading. Clearly, water column attenuation (α_w) is involved, which in the South Pacific(ref.18) is given by

$$\alpha_w = 0.07\ f_K^2/(1 + f_K^2) + 0.011\ f_K^2 \text{ dB/km} \tag{6}$$

where f_K = frequency in kilohertz. The water column attenuation model used in DUNES depends upon ocean with the expressions given in reference 19.

A further frequency independent term is frequently added to account for scattering which directs energy out of water column modes into the bottom. According to Guthrie's model(ref.20) the oceanographic scattering component has the form

$$\alpha_{os} = 1.1 \times 10^{-1}\ e^{-\chi/h} \text{ dB/km} \tag{7}$$

where h is the characteristic depth (200 m) and χ is the depth (m) on a propagation path. This is an empirical result based on analysis of bomb arrival time data. Thus it can be seen that the attenuation of ray paths which traverse near to the surface will be higher than those which are confined to deeper parts of the water column. This process can be expected to scatter energy into higher angles - some of which being lost into the bottom (hence the extra attenuation in water borne components). Not all this energy is, of course, lost to the sea floor. However, it does imply a transfer of energy into bottom-bounce modes.

The investigation of these effects will require a rather specific experiment and is beyond the precision available with data available to the authors. Although these possibilities are recognised, the model does not at present attempt to emulate them. A value of 0.0009 dB/km is added to the water column attenuation for all oceans.

2.5 The RSR component - noise contribution

Gathering together equations (4) and (5) above, the transmission loss law for RSR including dipole and monopole contributions is (in decibels terms)

$$L_{RSR} = 70 + 10 \log R + \alpha R - 10 \log D \tag{8}$$

where D = Dipole decoupling term modified
= $2.1 - \sin(4\pi z \Theta_1)/(2\pi z \Theta_1)$

In intensity terms, the loss function is:

$$l_{RSR} = De^{-\alpha' r}/(ar) \tag{9}$$

where $10 \log a = 70$, $r = R$

and $\alpha' =$ attenuation in nepers/kilometres.

Consider an element of the ocean surface as in figure 6. The area of the annular element (dAE) is

$$dAE = 2\pi r \, dr \tag{10}$$

Hence the noise contribution of this element at the receiver is (using equations (9) and (10))

$$di_{RSR} = D2\pi/(a) \, s_k \exp(-\alpha' r) \, dr$$

where s_k = surface source level per kilometres^2.

Hence the total received noise

$$\begin{aligned} i_{RSR} &= D2\pi/(a) \, s_k \int_{r_o}^{r_1} \exp(-\alpha' r) \, dr \\ &= D2\pi/(a\alpha') \, s_k \, [\exp(-\alpha' r_o) - \exp(-\alpha' r_1)] \end{aligned} \tag{11}$$

where r_o and r_1 are the initial and final ranges of integration. In decibel units

$$\begin{aligned} I_{RSR} = \; & S_k + 8 - A - 10 \log \alpha' + 10 \log D \\ & + 10 \log(\exp(-\alpha' r_o) - \exp(-\alpha' r_1)) \end{aligned} \tag{12}$$

where $S_k = 10 \log s_k$, $8 = 10 \log (2\pi)$ and $A = 10 \log a$. (Note $\alpha' = 0.23 \, \alpha$, where α is in decibels/kilometres.) The characteristics of the expression can be judged by reference to figure 7. Here I_{RSR} is plotted as a function of r_1 (ignoring the dipole term 10 log D) and shows the sensitivity of the RSR prediction to integration range. At 300 Hz the prediction has got to within 3 dB of its asymptotic value ($r_1 = \infty$) at a range $r_1 = 200$ km. At 50 Hz the 3 dB point does not occur until a range $r_1 = 4000$ km. Hence, the low frequency noise contribution due to RSR extends to considerable ranges from the receiver. The model implementation allows for bathymetric blockage to limit this range in each of four quadrants to account for practical geographical effects.

In terms of sensitivity to the initial range of integration (r_o), figure 7 shows this to be small for r_o less than 200 km. The model therefore uses the arbitrary initial range of 20 km to represent the beginning of RSR noise contribution. At frequencies above 1 kHz the sensitivity will be greater but the total contribution will be much lower than that at lower frequencies and therefore the errors with respect to the total noise are not important.

The addition of the dipole term in equation (12) reduces levels shown in figure 7 by typically 10 dB. This dipole term is most sensitive to the source depth parameter (z). As discussed earlier, it has been found that source depth needs to be both wind speed and frequency dependent before predicted values at low frequencies agree with measurement. At high frequencies the monopole contribution is found to dominate and z is of less importance.

The resultant RSR noise characteristics are summarised in figure 11 for various wind speeds and frequencies. The energy is received over the small vertical angle band $\cos^{-1}(C_o/C_s)$ to $\cos^{-1}(C_o/C_B)$ where C_o, C_s and C_B are sound speeds at the receiver, surface and bottom respectively (as in figure 2). The contribution is isotropic unless bathymetric effects limit the propagation from certain azimuths. There is no RSR noise unless $C_s < C_B$.

2.6 The bottom-bounce component - transmission loss

In the transmission region where acoustic mode stripping occurs due to bottom interaction (Weston(ref.21), Denham(ref.22)), propagation loss is of the form

$$L_{BB} = A + 15 \log R + \alpha R \qquad (13)$$

However, where the source is near to the surface, transmission loss approaches a 25 log R law due to the influence of the surface dipole. Denham(ref.22) has estimated that transmission loss for the bottom bounce component for near surface sound sources in the mode stripping region is (approximately)

$$l_{BB} = 1/a\ r^{-3/2} \cdot g_o(r) \cdot \exp(-\alpha' r) \qquad (14)$$

where $g_o(r) = 1 - \exp\{-(k_o h_s)^2\ H/(rQ)\}$

$k_o = 2\pi/\lambda\ (m^{-1})$

h_s = source depth (m)

H = water depth (km)

$Q = \alpha_s/20 \log e$

$\alpha_s \simeq 57 \times 0.05\ (f/25)^{1.5}$ = slope of bot. loss (dB/rad)

$\simeq 3\ (f/25)^{1.5}$

α' = water attenuation (nepers/km)

Denham showed reliable predictions for experimental data. This transmission loss law is also found to predict the results of PE

calculations reasonably well over frequencies and distances of interest (figure 8). The calculations were made for a 4748 m deep bottom limited propagation case with a realistic geoacoustic model for the sea floor. The sound speed profile was from the Indian Ocean with $C_s - C_B = 9.5$ m/s. Thus a realistic sound speed profile case also can be approximated by equation (14). The bottom loss slope parameter (α_s) has been found to be of prime importance. The simple form used (as above) attempts to distil global frequency and geographic variability into one simple expression. An expression for α_s can be derived(ref.23,24) giving

$$\alpha_s = cf^n \text{ (dB/rad)}$$

where c is a variable using density and sound speed ratio terms and the sea floor sediment compressional wave attenuation coefficient. The value of n for shallow water sediments is usually between 0 and 1(ref.23,24). We have chosen n = 1.5 based upon examination of bottom loss data for deep oceans. Final usage of the noise model has shown that regional changes in this parameter are justified although no scheme has currently been devised to quantify this. The current model allows the user to select a constant multiple of the above simple expression for α_s and retains the same frequency law at all locations.

To see the essential loss law operating, the following simplification is made(ref.22):

$$g_o(r) \simeq (k_o h_s)^2 H/(rQ)$$

when r is greater than $6.8\ H/\alpha_s\theta_c^2$ and θ_c is the critical angle on the bottom loss profile.

Hence

$$1_{BB} \simeq H(k_o h_s)^2/(Qa)\ r^{-5/2} \exp(-\alpha' r) \tag{15}$$

or in decibels

$$L_{BB} = A + 25 \log r + \alpha r - 10 \log (4\pi^2 h^2 H/Q)$$

where h is the source depth in units of wavelength.

Assuming A = 63

$$L_{BB} = 37 + 25 \log r - 10 \log (h^2 H/\alpha_s) + \alpha r \tag{16}$$

(Note $\alpha' = 0.23\alpha$ where α is in decibels/kilometres)

Thus we can see that for near surface sound sources the propagation loss has a 25 log R law with a dependence on source and water depth.

2.7 The bottom bounce component - noise contribution

2.7.1 Dipole contribution

The transmission loss for the bottom bounce component including surface dipole effects (equation (16)) is in the form

$$\text{Loss} = kr^{-5/2} \exp(-\alpha' r) \tag{17}$$

where

$$k = 4\pi^2 h^2 H/(a\alpha_s) \ . \ 20 \log e$$

$$= 342.9 \ h^2 \ H/a\alpha_s$$

To assess the bottom bounce component of noise from a distributed surface source having the above transmission characteristics the contribution from annuli are integrated (eg figure 6).

The area dA of the annulus at range r is

$$dA = 2\pi r \ dr$$

Thus the total noise contributed by the annulus is

$$di_{BB} = 2\pi r \ . \ s_o \ . \ k \ r^{-5/2} \exp(-\alpha' r)$$

Thus the integrated noise contribution between ranges r_1, r_2 is

$$i_{BB} = 2\pi \ s_o \ k \int_{r_1}^{r_2} \exp(-\alpha' r) \ . \ r^{-3/2} \ dr$$

Let

$$x^2 = \alpha' r$$

Then

$$i_{BB} = 4\pi\sqrt{\alpha'} \ s_o k \int_{x_1}^{x_2} \exp(-x^2)/x^2 \ dx$$

where

$$x_1 = \sqrt{\alpha' r_1} \quad \text{and} \quad x_2 = \sqrt{\alpha' r_2}$$

Then

$$I_{BB} = 4\pi\sqrt{\alpha'}\ s_o k \int_{x_1}^{x_2} 1/x^2[1-x^2 + x^4/2! - x^6/3! + \ldots]\ dx$$

$$\simeq 4\pi\sqrt{\alpha'}\ s_o k \int_{x_1}^{x_2} (1/x^2-1)\ dx \qquad \text{if } (x^2<1)$$

$$= 4\pi\sqrt{\alpha'}\ s_o k\ [1/x_1 - 1/x_2 + x_1 - x_2]$$

Hence taking logs and evaluating all constants, this becomes:

$$I_{BB}(dB) = S_o - 26.67 + 10 \log (h^2\ H/\alpha_s) + 5 \log \alpha'$$
$$+ 10 \log [1/\sqrt{\alpha' r_1} - 1/\sqrt{\alpha' r_2} + \sqrt{\alpha' r_1} - \sqrt{\alpha' r_2}] \qquad (18)$$

where $S_o = S + 60$.

The values of r_1 and r_2 are determined by simple geometry and test calculations as $r_1 = (2H - h_r)/\tan \Theta_c$ and $r_2 = 100$ km. The angle Θ_c is the critical angle defining the boundary between the BB and direct path components shown in figures 1 and 2. The receiver depth is h_r(m). At high frequencies x_2 becomes greater than 1 so the approximation to the integral is not accurate. However, tests show that the monopole contribution given in the next section dominates in this case.

2.7.2 The monopole contribution

Comparison between model predictions based solely on the dipoie contribution above and noise measurements show major discrepancies at low frequency. The dipole-only model predicts much lower values than those observed. In common with other workers (eg Wagstaff(ref.25), Wilson(ref.8)), this characteristic has been ascribed to the fact that there is not complete cancellation between direct and surface reflected components contributing to the dipole. While there are several ways of rectifying this, the appropriate approach still cannot be suggested since actual physical mechanisms are not yet confirmed. However the interim solution adopted in the DUNES model is to add a monopole contribution to the dipole contribution. This fills in the dipole null and implies that the source mechanism has two components.

The monopole contribution is assumed to have transmission loss as in equation (13) which applies to propagation in the model stripping region for a deep source. This expression therefore describes transmission without dipole effects - viz

$$i_m = \frac{1}{a} r^{-3/2} \cdot \exp(-\alpha' r)$$

Integrating the intensity of an annulus of surface energy in the same manner as the dipole contribution yields

$$di_{mono} = 2\pi r \cdot s_m \cdot r^{-3/2} \exp(-\alpha' r) / a \, dr$$

The integrated intensity is

$$i_{mono} = 2\pi \, s_m/a \int_{r_1}^{r_2} e^{-\alpha' r}/\sqrt{r} \cdot dr$$

let

$$x^2 = \alpha' r, \; x_1^2 = \alpha' r_1 \quad \text{and} \quad x_1^2 = \alpha' r_2$$

then

$$i_{mono} = 4\pi s_m/(a\sqrt{\alpha'}) \int_{x_1}^{x_2} e^{-x^2} dx$$

so

$$i_{mono} = 2\pi s_m \sqrt{\pi}/(a\sqrt{\alpha'}[\mathrm{erf}(x_2) - \mathrm{erf}(x_1)]$$

Taking logs and evaluating constants,

$$I_{mono} = 10.46 + S_m - 63 - 5 \log \alpha'$$

$$+ 10 \log [\mathrm{erf}(\sqrt{r_2\alpha'}) - \mathrm{erf}(\sqrt{r_1\alpha'})] \qquad (19)$$

(Note $\alpha' = 0.23 \; \alpha$ where α is in decibels/kilometres). S_m is the monopole source level ie S_o - 10 dB. Again r_1 is given by geometry. The value of r_2 is taken to be 5000 km unless there is bathymetric

blockage. Estimates of the bottom bounce component involve the evaluation of dipole (equation (18)) and monopole (equation (19)) components. They are combined by power summation. Under average conditions, these are graphed in figure 11.

2.8 The extra down-going components

2.8.1 The bottom bounce sector

Within the same angle sector as bottom bounce energy there is an additional component which arrives in the downward direction only. This component is received directly from the ocean surface from an annulus defined by the intersection at the surface of angles $\Theta_1 = \cos^{-1}(C_o/C_B)$ and $\Theta_2 = \cos^{-1}(C_o/C_{BB})$ as in figure 2. For the case of $C_o > C_B$ then $\Theta_1 = 0$.

Since this component does not have bottom interactions it is best described in the same way as RSR paths, namely by equation (12).

However, in this case a more general form of the dipole loss term is required to recognise a non-zero lower angle limit to the integration of the dipole function. The equivalent expression to equation (5) for the

$$D_{down} = 2 - (\sin 4\pi z\Theta_2 - \sin 4\pi z\Theta_1)/(2\pi z(\Theta_2 - \Theta_1)) \qquad (20)$$

This dipole loss is in addition to simple cylindrical spreading from the source annulus to the receiver. Using the same expression for received noise (I_{down}) as was developed for the RSR case (cylindrical spreading) we obtain (from equation (12))

$$I_{down} = S_k + 8 - 70 - 10 \log \alpha' + 10 \log D_{down}$$

$$+ 10 \log (\exp(-\alpha' r_o) - \exp(-\alpha' r_1)) \qquad (21)$$

The ranges of integration (r_o, r_1) can be estimated from the geometry of the situation as $r_o = h_r/\tan\Theta_2$ and $r_1 = h_r/\tan\Theta_1$. These are typically 300 m and 800 m respectively for the case of a 200 m receiver depth. The corresponding value of the downward component described by equation (21) is shown graphically in figure 9(a) as a function of wind speed and frequency. By comparison, the bottom bounce component is shown in figure 9(b). It can be seen from these figures that the downward component is insignificant compared with the bottom bounce component at frequencies below 1 kHz and therefore does not affect estimates of noise in the relevant vertical angles. However, for the case of a deep ocean, deep receiver at higher frequencies this extra component can be important and it is included in DUNES. The effects are seen in the examples in Appendix I.

2.8.2 The RSR sector

There should be an additional downgoing component included in the RSR angle sector between Θ_1 and Θ_o. However this is not currently included in DUNES 2.3. Again it will only be important at high frequencies.

2.9 The direct path component

The final wind generated noise component considered within the DUNES model is that arriving directly from the surface at angles above $\cos^{-1}(C_o/C_{BB})$ or an equivalent critical angle (see figure 2). An estimate which relates to this has been offered by Burgess and Kewley(ref.5). Their approach, based on an energy flux argument, results in a noise level N, where,

$$N = S + AB + 8 \tag{22}$$

where

$$AB = 10 \log ((b + 1)/(b - 1)) \tag{23}$$

b = bottom reflection loss at vertical incidence

= $\text{antilog}_{10}(\beta/10)$

and β = bottom loss in decibels

This noise estimate assumes in essence that the direct path contribution defined above extends across all vertical angles. It is necessary to remove from this estimate noise outside the angles of interest - namely noise within $\pm\Theta_L = \cos^{-1}(C_o/C_{BB})$. Since energy coming at the receiver from angles below horizontal have one more bottom interaction than those incident from above, the energy N in equation (22) has to be separately apportioned into up and down components. Some discussion of this is given in reference 5.

Based on this, it can be shown that the up and down components of direct path noise are, respectively

$$I_{up} = S + 8 + 10 \log a_u + 10 \log E \tag{24}$$

$$I_{down} = S + 8 + 10 \log a_d + 10 \log E \tag{25}$$

where $E = 1 - \sin\{\cos^{-1}(C_o/C_{BB})\}$

$a_u = \exp(-z\alpha')\exp(-(H-z)2\alpha')/(b-\exp(-2H\alpha'))$

$a_d = b\exp(-z\alpha')/(b-\exp(-2H\alpha'))$

z = the receiver depth (km)

α' = the water column attenuation (nepers/km)

H = water depth (km)

In the limits of low frequency and no attenuation

$$a_u = 1/(b - 1)$$

$$a_d = b/(b - 1)$$

which are the limits used to derive equation (23). In the limit of b = 1 the above expressions allow a_u and a_d to stay finite. The expressions also reduce the amplification for high frequencies by including attenuation.

The values of vertical incidence bottom loss used in the DUNES model are derived from measurements taken from Burgess and Kewley(ref.5). Figure 10 (based on figure 11 in reference 5) shows the frequency dependence of measured vertical incidence bottom loss at various sites in the southern hemisphere. The trend is simulated by the modified sinusoid which is also plotted on the figure.

The sinusoid has the form

$$\beta = 2.9 + 2 \sin (3.5 \log f - 6.82) \text{ (dB)} \tag{26}$$

The sinusoid is modified by fixing the predicted value below 32 Hz at 0.9 and above 500 Hz at 3.88.

Predicted levels of the direct path wind noise component are shown in figure 11. A correction factor is also shown which accounts for the effect of moving the simulated normal incidence bottom loss (figure 10) up and down to high and low loss extremes. The final minimum loss is set at 0.5 dB.

2.10 The shipping component

Although the DUNES model has been motivated by a need to predict and understand wind generated noise it also contains estimates of the shipping contribution. In most southern hemisphere locations of interest, this contribution is difficult to predict because the ship densities are low and good historical information not available. The shipping contribution is commonly the result of a few local vessels whose position cannot be predicted easily and whose source spectrum is not known. There is, nevertheless a clear need to include ships since in some instances their position is known. There is also interest in assessing the relative contribution of ships compared to wind generated noise at various locations and frequencies. For these reasons, shipping has been included even though in some instances with less detailed description than corresponding wind noise components.

2.10.1 Source spectrum

One of the greatest problems in assessing the ship component is not knowing an appropriate source spectrum. The source level of a ship depends upon ship speed, horsepower, mechanical condition and the sea state. These factors vary in a way which is hard to predict. Under conditions of high ship density, some advantage can be taken of generalised ship statistics where individual ship variation is absorbed in the overall picture. This approach has been adopted by some authors(ref.26,27) and has greatest relevance in high shipping density areas. In regions where ship noise is controlled by a few individual ships, a more specific prediction based on noise from ship classes is more desirable. In most instances, however, specific ship passages cannot be predicted with sufficient precision and probabilistic solutions must be sought. To this end some initial surveys were taken of ship traffic around New Zealand(ref.28). The general distribution of ship length (which correlates broadly with source level) was shown to be similar to world wide distributions (figure 12). The most likely ship length is around 600 ft which applies to general cargo vessels. Heine(ref.27) has reported on measurements of such a vessel and these are summarised in figure 13 for the broadband radiation. Specific frequency lines will be up to 10 dB higher than the continuous spectrum but these are not the subject of the noise prediction. Line clutter is regarded as easily distinguishable from background noise and falls within the field of target identification.

The general shape of the continuous spectrum (figure 13(b)) can be described by three parameters - low frequency slope, high frequency slope and peak level. Low frequency roll-off is determined by surface dipole effects and should be included as part of the transmission loss not source level. However, this involves estimating effective source depth of ship radiation and a level of investigation beyond the needs of the DUNES model. The low frequency roll-off is retained as 6 dB/octave in the model. The high frequency slope (15 dB/octave) has been found to be too steep and so 10 dB/octave is in the model. Measured shipping noise examples are seen in reference 29 (figures 2 to 6, 2 to 9 and 2 to 14). Maximum source level is an input parameter in DUNES. The default value of 167 dB (as in figure 13(b)) seems to produce acceptable noise predictions under conditions where ship noise predominates.

2.10.2 Enhanced ships

It is well established that sources over distant bathymetric slopes or at high latitudes give rise to enhanced noise contributions. This was discussed in connection with wind generated noise in Section 2.3.

Ship sources in such situations are dealt with in either of two ways depending whether it is easier to describe them as individual vessels or as a continuous ship lane.

The noise contribution from individual ships (L_{SH}) is estimated using a cylindrical spreading transmission loss, viz

$$L_{SH} = S - 70 - 10 \log R - \alpha R \qquad (27)$$

where S = ship source level at a given frequency
R = range to the receiver (km)
α = water column attenuation (dB/km)

If the shipping distribution is best described as a continuous lane, then a modified form of equation (3) (Section 2.3) is used.

The noise contribution (I_{SL}) of a ship lane at a distance R from a receiver is

$$I_{SL} = S_A - 70 - 3 + K - \alpha R \sqrt{x_1^2/4R^2 + 1} \qquad (28)$$

where S_A = source level of shipping per kilometres
= $S + 10 \log (S_N/x_1)$
S = single ship source level (dB) re 1 μPa^2/Hz at 1 km)
S_N = number of ships on lane
x_1 = half the length of the symmetrical ship lane (km)
R = CPA range of lane to receiver (km)
K = $10 \log [\ln(x_1/R + \sqrt{x_1^2/R^2 + 1})]$
α = water column attenuation

The noise contribution predicted by equations (27) or (28) come by way of RR paths as defined in figure 2.

2.10.3 Local ships

The transmission of noise from local ships is via RSR, bottom bounce and direct paths in a way analogous to wind generated noise (Sections 2.4 to 2.9). This approach, however, involves the complication of needing to know the source depth of ship noise radiation which is difficult to estimate. Consistent with the approach described in Section 2.10.2, a single transmission loss is used, which relates only to bottom bounce modes. It is found that spherical spreading transmission loss plus attenuation provides a reasonable approximation over the shipping frequency band for shallow sources. While this description does not allow for different bottom loss values it represents the current implementation in DUNES and has been found to give useful results.

Accordingly, the case of discrete ships is handled as follows. The received level (I_{SH}) is given by receiver is

$$I_{SH} = S - 60 - 20 \log R - \alpha R \qquad (29)$$

where S = ship source level (Section 2.10.1)
R = range to receiver (km)
α = water column attenuation (dB/km)

When local shipping is most easily described as a uniform shipping lane, then the noise contribution is approximated by

$$R_{SH} = S_A - 60 + 3 - 10 \log R + 10 \log (\tan^{-1} x_1/R) - \alpha R\sqrt{1+(x_1/2R)^2} \qquad (30)$$

where parameters are the same as for equation (28). The local ship noise contribution calculated from either equations (29) or (30) is assumed to cover the vertical angle range relevant to bottom bounce transmission as defined in figure 2. There is no calculation of the RSR (convergence zone) contribution since this requires information which is too specific geographically. The level of the bottom bounce contribution is extended to cover the RSR vertical angle range (figure 2) to avoid discontinuities. If a ship is known to be present and within a convergence zone, its contribution can be estimated using equation (27). This is relevant since transmission loss from a convergence zone follows approximately a cylindrical spreading law.

2.11 Storm noise component

Following the development of shipping lane contributions to the noise, a component of wind generated noise due to non local storms is easily formulated. Long distance high latitude storms and coastal enhanced storms are readily accounted in the previous sections while a local storm is incorporated in the direct path component. The storm is modelled as a finite width lane transmitted via bottom bounce modes in the same manner as local ships in Section 2.10.3.

Thus the received level due to storms is given by

$$I_{ST} = S + 10 \log W - 60 + 3 - 10 \log R + 10 \log (\tan^{-1} x_1/R) - \alpha R\sqrt{1 + x_1^2/4R^2}$$

where S = source level of storm noise per kilometres^2
R = range to storm (km)
x_1 = half the length of storm (km)
W = width of storm (km)

Follow the local ship procedure, the noise contribution is assumed to cover the vertical angle range relevant to bottom bounce transmission and extended to the RSR range to avoid discontinuities. Locating a storm over a known convergence zone region can be simulated by using the slope enhanced description as the propagation law is then more appropriate however the angular spread will be wrong.

2.12 Receiver depth effects

It has been observed that the location of the receiver close to the sea surface can cause a reduction in noise level due to surface decoupling effects. Thus the components of noise via BB, RSR, and RR paths will be increasingly sensitive to the depth of the receiver. The following reduction factors are used to account for this effect.

First the decoupling depth (in wavelengths) for each component is found using

$$d_{RR} = 0.25/\sin(\Theta_{RR}/2)$$

$$d_{RSR} = 0.25/\sin(0.5(\Theta_{RR} + \Theta_{RSR}))$$

$$d_{BB} = 0.25/\sin(0.5(\Theta_{BB} + \max(\Theta_{RR},\Theta_{RSR})))$$

where $\Theta_{RR} = \cos^{-1}(C_o/C_s)$

$\Theta_{RSR} = \cos^{-1}(C_o/C_B)$

$\Theta_{BB} = \cos^{-1}(C_o/C_{BB})$

These depths correspond to the first maximum for the Lloyd mirror interference pattern. The average arrival angle for each noise component is used to approximate the typical decoupling depth.

If the receiver depth (in wavelengths) is less than these decoupling depths then the reduction factors are given by:

$$f_{RR} = \sin^2(2\pi z/(4d_{RR}))$$

$$f_{RSR} = \sin^2(2\pi z/(4d_{RSR}))$$

$$f_{BB} = \sin^2(2\pi z/(4d_{BB}))$$

where z is the receiver depth in wavelengths(ref.30). More precise estimates can be made using the actual sound speed profiles(ref.30) rather than the first order isospeed assumptions used here.

3. RUNNING THE FORTRAN PROGRAM

3.1 General

In its present form the model is set up to operate either interactively from a terminal or from a file of input parameters. In either case, the main issue is an appropriate definition of input values and this is the point to be discussed in this part of the report.

The inputs are generally not required to be specified with great precision. The concept of the model is in terms of generalities and averages so the inputs can reflect this philosophy. The decibel law allows for considerable input latitude before output levels (dB) are affected greatly.

Appendix I reproduces a typical terminal session annotated with additional components. In what follows in this part of the report, the individual input parameters and options are discussed with the aim of assisting a user to define input values appropriate to a specific modelling requirement.

3.2 Parameter inputs

Reference to Appendix I will show that the program inputs can be conveniently grouped into: initial parameters, environmental, local noise,

distant noise and shipping inputs graph format options and output data options. These separate sets of inputs are discussed in following Sections.

It has been found convenient to use an input worksheet to assist in organising parameters relevant to a given site and situation. The worksheet is shown in Appendix II in blank form and in completed form with data used in the test run to be described.

3.2.1 Initial parameters

The implementation at WSRL on an IBM 3033 is initiated by a CLIST command which is set up to run the program. For the VAX and IBM PC versions similar DCL and BAT files can be used, respectively.

3.2.2 Environmental inputs

The next set of inputs (Appendix I) define the environment.

(a) Ocean area

This is used to select from data within the program appropriate parameters for the high latitude wind contribution and sound attenuation. These are found in subroutines HLAT and ATTENU.

(b) Receiver latitude

Used in subroutine HLAT to determine distance from high latitude winds. It is also used to distinguish the North and South Atlantic and Pacific Oceans in ATTENU.

(c) Season

Also used only in HLAT in initial parameter definition. The two seasons recognised in the program are southern summer (February) and winter (August).

(d) Receiver depth (metres)

This is used in subroutine LOCAL in the area used to estimate the bottom bounce component. The specific significance of receiver depth is in the calculation of the initial range of integration (r_1 in equation (18)). This is the range from the receiver which corresponds to the surface interaction of the ray which just grazes the bottom and passes through the receiver. The depth is also used for decoupling factors.

(e) Sound speeds (m/s) and water depth (km)

In order to calculate the vertical angle limits which correspond to various noise components, sound speeds at the receiver location need to be specified (see figure 2). Parameters required are sound speeds at the surface, receiver depth and bottom. The water depth also needs to be specified.

(f) Range of transmission blockage

At low frequency, the RSR component can be affected by surface noise to many thousands of kilometres (figure 7). This distant component would, however, be removed if bathymetric or land mass blockage

intervened. To allow for this possibility, the range to significant transmission blockage (in thousands of kilometres) is specified in each of four quadrants if near to a coastal margin, for example 2 quadrants could be set to 0.1 thousand kilometres (100 km) the remaining 2 quadrants to the default value of 5 (5000 km) to indicate no blockage. The quadrants are centred upon the NSEW directions to provide azimuthal variation.

3.2.3 Local wind noise inputs

(a) Slope of bottom loss versus angle

Bottom loss is used in the model as the slope of the bottom loss versus angle (equation (14)). This is calculated internally as a function of frequency in a way which seems to give good agreement with average transmission loss estimates. The model input is a scalar which is a simple multiplier of the decibels per radian average bottom loss estimate. A multiplier greater than one applies to high loss areas and less than one to low loss areas.

(b) Vertical bottom loss

The vertical bottom loss is used to assess direct path local wind noise (equations (22), (23)). The internal calculation is based on figure 10. The input control over vertical bottom loss is simply to move the average curve (figure 10) up or down a specified number of decibels. The range of measured values shown on figure 10 implies that input limits of ±1.2 dB covers the range. It should be noted that the model limits internally the vertical bottom loss to be greater than 0.5 dB for any input conditions.

(c) Local noise angle limits

Energy received within vertical angles which correspond to rays hitting the sea floor above the critical angle is treated separately from the bottom bounce component and is termed 'local' noise. The angle limits which apply to this component are between the vertical (up and down) and an angle specified in either of three ways as program input. Firstly, the angle can be specified directly. Suggested values are the angle with bottom loss -3 dB down from the 90° value or the angle of intromission if $C_o/C_{BB} > 1$. Secondly, it can be calculated from the bottom critical angle if the sub-bottom sound speed is given. Thirdly, a default condition assumes the sub-bottom sound speed is 10% greater than the water sound speed (previous input) at the sea floor.

(d) Help sheet

Appendix III shows a help sheet to use when determining what angles and losses to use for the local wind noise inputs.

3.2.4 Distant wind noise inputs

The distant wind noise components are defined here as originating at high latitudes on bathymetric slopes. These components are assumed to be RR transmission types (Section 2.4).

(a) Fraction of high latitude wind and their bearings

This input allows the user to enter an estimate of the fraction of the high latitude wind band which is acoustically visible from a given receiver location. This is intended to provide the means of dealing with bathymetric or land mass blockage. The bearings are usually 0° and 180° but can be changed to allow for blockage in those directions.

(b) Slope enhanced wind lanes or storms

One option here is to specify no wind lanes, however a default lane is available as a rough average of the contribution from wind noise enhanced by bathymetric slopes. The specification of the default lane is 1500 km long, 100 km wide at a distance of 500 km and 270° from the receiver. A 12 kn wind is assumed to be blowing over the region. Alternatively, wind lane or storm data above can be entered for up to 5 independent slope enhanced or storm regions. Their bearings provide the azimuthal variation. Note that the lanes are assumed to be symmetrical about their point of closest approach.

3.2.5 Shipping inputs

Up to five independent shipping inputs may be specified (or no inputs if required). Shipping inputs are in two forms - either as a shipping lane or as individual discrete ships. In each of these categories the ships can be specified as enhanced or not. The enhanced option implies transmission loss relevant to ideal down slope propagation over bathymetric features. This option (for discrete ships) is also suitable for a vessel known to be in a convergence zone.

If a ship lane is specified then lane length and total number of vessels on the lane is required. Note that the lane is assumed to be symmetrical about its point of closest approach. In all cases of ship input the source spectrum is specified by a peak level and a frequency at which the upper roll-off (10 dB/octave) begins. The bearings are needed for azimuthal variation.

3.2.6 Output graphics options

There are two output wind speed options - either to specify a wind speed (5 to 40 kn) for full plot of all noise components at that wind speed - or to request total omnidirectional noise at all wind speeds to be shown. These two options are shown in Appendix I (g and i). There are also plots of vertical and horizontal noise directionality available on request.

The units of the vertical noise can be specified as either total omnidirectional energy (dB re 1 $\mu Pa^2/Hz$), or energy per steradian (dB re 1 $\mu Pa^2/Hz$ - sr). The latter units are used in most prediction models to compare with data.

3.2.7 Output data options

Tables of omnidirectional, vertical, horizontal and three dimensional noise are available to be output before DUNES finishes. The first three files are Formatted while the last is Unformatted. The outputs are in columns of two as in the following examples

OMNI	VERTICAL	HORIZONTAL	THREE-D
0 200(N) 10.0 96 . 10000 55 . . N Pairs of Frequency-level	0 20(M) 10.0 14(N) -90 76 . 90 79 20.0 14 -90 50 . +90 56 . . M Frequencies N Angle-level Pairs	0 20(M) 10.0 36(L) 0 76 . . 359.9 70 20.0 36 0 50 . . 359.9 65 . . M Frequencies L Bearing-level Pairs	0 36(L) 0.0 20(M) 10.0 14(N) -90 76 . . 90 79 20.0 14 -90 50 . . 90 56 . . 359.9 20 10.0 14 -90 53 . . 90 76 . . L Bearing Angles M Frequencies N Angle-level Pairs

3.3 Final notes

Some notes on IBM PC usage are provided in Appendix IV. If errors or deficiencies are found in the DUNES model the authors would be pleased to know about them to ensure upgrading of the model can continue.

4. CONCLUSIONS

At present the ability of the current model to be extended to lower frequencies and to shallow water (<200 m) is being investigated. The FORTRAN 77 code is available from the authors.

The development of the DUNES model presented here explains the methods used and why it has proven to be an effective model in giving realistic predictions of noise level and directionality. However, there are a number of assumptions made by the authors regarding source depths and directionality and only further studies in these fields will resolve their true forms. We believe that DUNES can be used to further our understanding of these phenomena.

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14	Neumann, G. and Pierson, W.J., Jr	"A Detailed Comparison of Theoretical Wave Spectral and Wave Forecasting Methods". Dtsch. Hydrogr. Z. 10, 73-92, 10, 134-146 (1957)
15	Dashen, R. and Munk, W.	"Three Models of Global Ocean Noise". J. Acoust. Soc. Am. 76, 540-554 (1984)
16	Bannister, R.W.	"Deep Sound Channel Noise from High Latitude Winds". J. Acoust. Soc. Am. 79(1), 41-48 January 1986
17	Bannister, R.W.	"The Missed Component - Noise from Winds at High Latitude". WSRL Tech. Report (to be published)
18	Bannister, R.W., Denham, R.N., Guthrie, K.M. and Browning, D.G.	"Project TASMAN TWO: Low-frequency propagation measurements in the South Tasman Sea". J. Acoust. Soc. Am. 62, 847-859 (1977)
19	Mellen, R.H., Scheifele, P.M. and Browning, D.G.	"Global Model for Sound Absorption in Sea Water". Technical Report NUSC TR-7923, 1 October 1983
20	Guthrie, M.K.	Private Communication DSE
21	Weston, D.E.	"Intensity - Range Relations in Oceanographic Acoustics". J. Sound Vib. 18, 271-287 (1971)
22	Denham, R.N.	"Intensity - Decay for Near-Surface Sources". J. Acoust. Soc. Am. 79(1), 60-63 January 1986
23	Eller, A.I. and Grershfeld, D.A.	"Low-frequency acoustic response of shallow water ducts". J. Acoust. Soc. Am. 78, 622-631 (1985)

No.	Author	Title
24	Zhou, J-x, Zhang, X-z and Rogers, P.H.	"Effect of frequency dependence of sea bottom attenuation on the optimum frequency for propagation in shallow water". J. Acoust. Soc. Am. 82, 287-292 (1987)
25	Wagstaff, R.A.	"RANDI: Research Ambient Noise Directionality Model". NUC TP 349, April 1973
26	Gray, Leslie M. and Greeley, David S.	"Source Level Model for Propeller Blade Rate Radiation for the World's Merchant Fleet". J. Acoust. Soc. Am 67(2), 516-522 February 1980
27	Heine, John C.	"Acoustic Source Characteristics of Merchant Ships". SACLANT Conference Proceedings No. 32 (Underwater Noise), Vol. 2 (SACLANTCEN LaSpezia, Italy, 15 June 1982)
28	Hunt, B.J.	"Report on Merchant Ship Characteristics around New Zealand". Applied Research Office Report, 1972, University of Auckland Private Bag Auckland, New Zealand
29	Urick, R.J.	"Ambient Noise in the Sea". Peninsula Publishing, Los Altos, Ca. (1986)
30	Bannister, R.W. and Pedersen, M.A.	"Low-frequency Surface Interference Effects in Long Range Sound Propagation". J. Acoust. Soc. Am. 69, 76-83 (1981)

APPENDIX I

TERMINAL OUTPUTS DURING DUNES RUN ON IBM AT WSRL

I.1 Initial parameters

```
DUNES2P3 PLOT(TEK)
FILE FT06F001 WAS ALLOCATED AND HAS BEEN FREED BEFORE THE CURRENT ALLOCATION.
FILE FT05F001 HAS BEEN ALLOCATED SHR.
FILE FT08F001 HAS BEEN ALLOCATED SHR.
FILE FT09F001 HAS BEEN ALLOCATED SHR.
FILE FT10F001 HAS BEEN ALLOCATED SHR.
FILE FT11F001 HAS BEEN ALLOCATED SHR.
```

I.2 Environmental inputs

```
DUNES (2.3) NOISE PREDICTION MODEL

--------------------------------------------------

GENERAL ENVIRONMENTAL INPUTS.......................     ) Needed for
ENTER OCEAN AREA: 1=PACIFIC, 2=INDIAN, 3=ATLANTIC       ) high latitude
?                                                       ) wind components
1

ENTER RECEIVER LATITUDE(DEGS)  -SOUTH NEGATIVE
?
-30

ENTER SEASON (1=FEBRUARY, 2=AUGUST)
?
1

ENTER RECEIVER DEPTH(M)..EG 200
?
200

DEFAULT SOUNDSPEEDS (M/S) ARE:
1520(SURFACE),1490(RECEIVER),1538(BOTTOM)
ENTER 1 TO ALTER THESE VALUES
?
1

ENTER SOUNDSPEED VALUES AT......
SURFACE,RECEIVER,BOTTOM (1520,1490,1538)
?
1527 1498 1539
SPECIFY WATER DEPTH (KM)..
?
4.5
ENTER RANGE (KMX1000) CLEAR OF TRANSMISSION BLOCKAGE    ) Important for
IN 4 QUADRANTS(0,180,90 AND 270 +- 45 DEGS              ) strong RSR
E.G. 5,5,5,5 IN MID-OCEAN)                              ) component
?
.1 .1 5 5
```

I.3 Local wind noise inputs

```
---------------------------------------------------

INPUTS FOR LOCAL WINDNOISE COMPONENT...............        ) High loss > 1
ENTER SCALE FACTOR FOR SLOPE OF BOTTOM LOSS VS ANGLE       ) Low loss < 1
(1=AVERAGE)
?
1
ENTER DB VARIATION FROM AVERAGE VERTICAL BOTTOM LOSS
(+1.2 AND -1.2 ARE HIGH/LOW EXPERIMENTAL LIMITS,0=AV)
?
0

 . . . . . . . . .TO DEFINE LOCAL NOISE LIMITS:
ENTER EITHER -   ANGLE LIMIT FOR LOCAL NOISE (DEG)
         OR -    SUB-BOTTOM SOUNDSPEED (M/S)               ) Default is 10% jump
         OR -    ZERO FOR DEFAULT                          ) in sound speed from
?                                                          ) water to bottom
0
```

I.4 Distant wind noise inputs

```
---------------------------------------------------

INPUTS FOR DISTANT WINDNOISE COMPONENTS ...........        ) To cover land mass
                                                           ) shadowing of high
ENTER FRACTION OF HIGH LATITUDE WIND REGION                ) latitude winds
(NORTH,SOUTH).....E.G. 1,1
?
0.5 1
NOW ENTER THE N AND S BEARINGS, USUALLY 0,180 DEG          ) Default lane is 1500 km
0 180                                                      ) 1500 km long, 100 km wide,
                                                           ) 500 km range, at 270°,
ENTER NUMBER OF SLOPE OR STORM WINDLANES                   ) enhanced with 12 kn winds
(-1=ONE DEFAULT SLOPE ENHANCED LANE; 0=NONE 5=MAX)
?
1

FOR WINDLANE NUMBER     1  ENTER FOLLOWING
LANE LENGTH (KM)
?
1000
 IS THIS A SLOPE ENHANCED LANE (Y/N)?
Y
LANE WIDTH (KM)
?
25
CPA RANGE FROM RECEIVER (KM)
?
100
 BEARING OF LANE FROM THE RECEIVER (DEG)
?
270
WINDSPEED AT WINDLANE (KNOTS)
?
15
```

I.5 Shipping inputs

```
-------------------------------------------------

INPUTS FOR SHIP CONTRIBUTION........................
ENTER NUMBER OF SHIP INPUTS TO FOLLOW (0 TO 5)
?
2

* * * * * * * * * * * * * * * * * * * * * * *
FOR SHIP INPUT NUMBER    1 ENTER FOLLOWING:
LANE LENGTH (KM)
(LANE LENGTH =0 INDICATES DISCRETE SHIP OPTION)
?
0
IS THIS SHIP CONTRIBUTION SLOPE ENHANCED? (Y/N):
Y
RANGE OF SHIP(S) IN KM
?
100
 BEARING OF SHIP(S) FROM RECEIVER (DEG)
?
73
NUMBER OF SHIPS AT RANGE AND BEARING
?
1
PEAK SOURCE LEVEL OF AVERAGE SHIP (E.G.165 DB)
?
165
AND FREQ. BREAKPOINT OF SOURCE SPECTRUM (E.G.60 HZ)
?
60

* * * * * * * * * * * * * * * * * * * * * * *
FOR SHIP INPUT NUMBER    2 ENTER FOLLOWING:
LANE LENGTH (KM)
(LANE LENGTH =0 INDICATES DISCRETE SHIP OPTION)
?
1000
IS THIS SHIP CONTRIBUTION SLOPE ENHANCED? (Y/N):
N
CPA RANGE FROM SHIP OR LANE TO RECEIVER (KM)
?
200
 BEARING OF SHIP OR LANE FROM RECEIVER (DEG)
?
270
AVERAGE NUMBER OF SHIPS (IF LANE TOTAL NUMBER)
?
20
PEAK SOURCE LEVEL OF AVERAGE SHIP (E.G.165 DB)
?
165
AND FREQ. BREAKPOINT OF SOURCE SPECTRUM (E.G.60 HZ)
?
60
```

Discrete ship option

Ship lane option

I.6 Output options

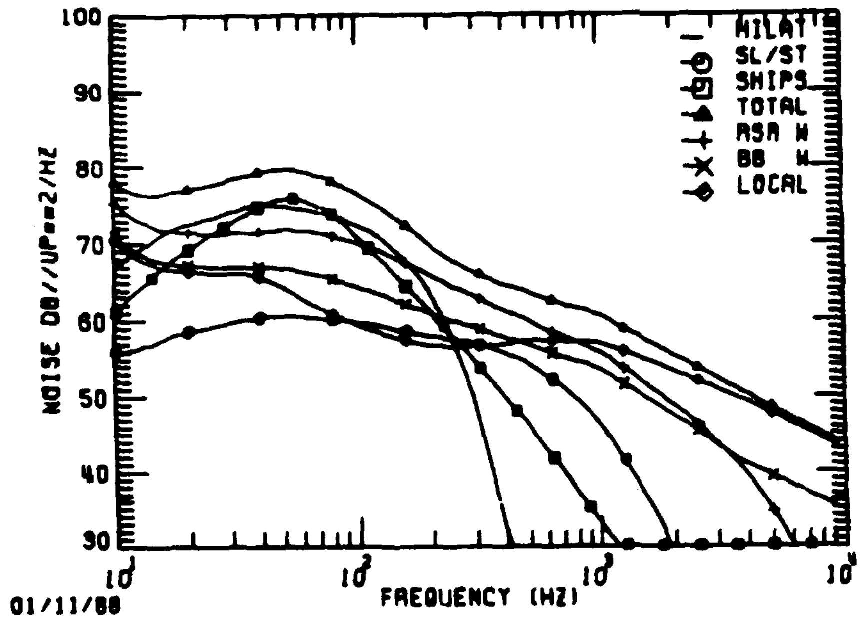
```
-------------------------------------------------

ENTER WINDSPEED FOR OMNI PLOT (KNOTS)
EITHER ONE VALUE BETWEEN 5....40 OR 0 FOR FULL RANGE
?
15

-------------------------------------------------

DUNES  PREDICTION IN PROGRESS

-------------------------------------------------
05/08/88:
 INPUT PLOT SIZE AND DEVICE UNIT
?
1,1
```

) Dummy values for IBM; VAX
) and PC values are not

I.7 Omnidirectional noise at specified (kn) wind speed with all components shown

DUNES 2.3 OMNIDIRECTIONAL NOISE

```
PACIFIC OCEAN  - FEBRUARY SHIP LANE PARAMETERS                  WIND LANE PARAMETERS
LATITUDE -30.0 DEGS
WINDSPEED :5.0 KNOTS        TYPE LEN  RANG SHPS LEVL PEAK BEAR  TYPE LEN  WIDTH RANG BEAR WSPD
BOT.LOSS GRADIENT: 1.0      SHIP+ 0    100 1    165  60   73    SLPE 1000  25    100  270  15
VERTICAL BOT.LOSS: 0.0      LANE  1000 200 20   165  60   270
WINDLANE FRACTIONS:
0.5 (N) 1.0 (S)
RD (M):200.DEPTH:4.50 KM
CS, CR, CB: 1527. 1490. 1530. QUAD. RANGE N. S. E. W: 100. 100. 5000. 5000. KM
```



I.8 Vertical directionality

ENTER VERTICAL NOISE UNITS (OMNIDIRECTIONAL/STERADIANS) OR QUIT VERTICAL NOISE SECTION..(O/S/Q)
NOTE THAT FOR VERTICAL DATABASE OUTPUT USE S, BEFORE Q
S
WINDSPEED = 15.0

SOUNDSPEEDS-SUR,REC,MIN,BOT: 1527.00 1498.00 1478.00 1539.00

ANGLE LIMITS-SG,BG,LOC: 11.2 13.3 27.8

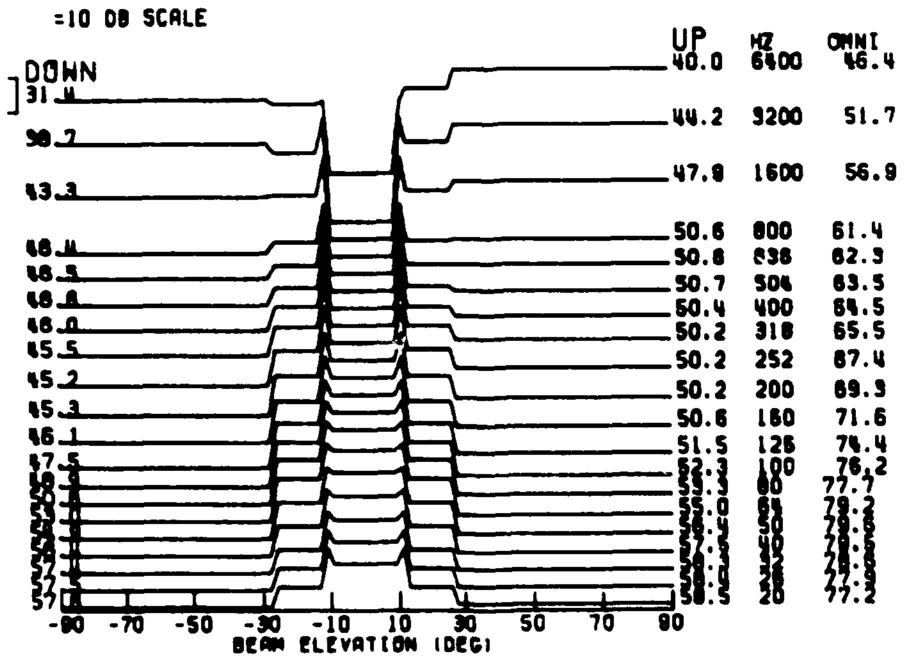
RR,RSR SWITCH FLAGS 1.000 1.000) Surface and bottom grazing

UNITS = DB//UPA**2/(HZ-STR)) angles and local angle limit

FREQ	BBU	BBD	RSR	RR	HIGHU	HIGHD	OMNI
20.	63.5	63.5	74.99	70.56	57.57	58.48	77.22
25.	63.9	64.0	75.00	71.66	57.47	58.38	77.88
32.	64.5	64.5	75.12	72.76	57.42	58.33	78.63
40.	65.4	66.4	75.40	73.93	56.43	57.54	79.50
50.	65.6	65.7	75.57	74.11	54.98	56.40	79.65
64.	65.2	66.2	75.47	73.68	52.99	54.97	79.24
80.	63.3	63.4	74.44	72.05	50.55	53.33	77.71
100.	61.6	61.7	73.49	70.35	48.93	52.34	76.18
125.	59.9	60.0	72.37	68.29	47.53	51.52	74.43
160.	57.8	57.9	70.55	64.68	46.05	50.65	71.63
200.	56.4	56.5	69.06	61.16	45.34	50.80	69.31
252.	55.3	55.5	67.73	57.49	45.21	50.16	67.39
318.	53.8	54.1	65.90	54.13	45.48	50.25	65.53
400.	52.8	53.1	64.55	52.49	45.90	50.42	64.46
504.	51.8	52.2	63.25	50.79	46.62	50.66	63.51
636.	50.4	51.0	61.61	48.02	46.48	50.60	62.26
800.	49.4	50.1	60.47	45.45	46.35	50.55	61.42
1600.	43.7	45.1	54.43	30.81	43.30	47.89	56.88
3200.	36.0	39.1	45.98	3.63	38.68	44.15	51.69
6400.	29.8	34.5	30.77	2.15	31.37	39.97	46.44

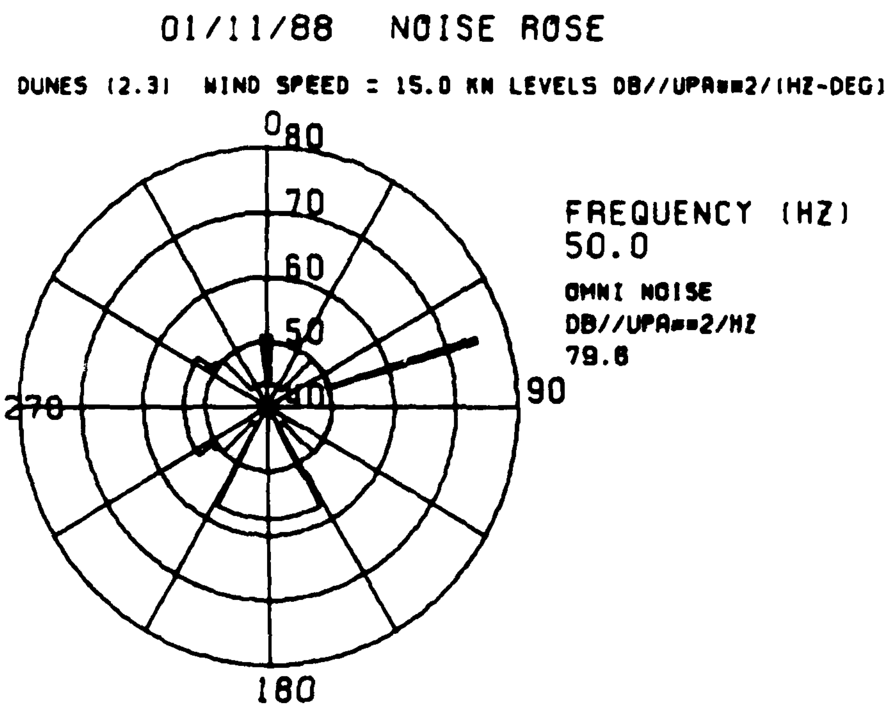
01/11/88 DUNES (2.3)

WSPEED = 15.0 KNOTS VERTICAL NOISE LEVELS DB//UPA**2/(SR-HZ)



I.9 Horizontal directionality

```
C

ENTER VERTICAL NOISE UNITS (OMNIDIRECTIONAL/STERADIANS) OR QUIT VERTICAL NOISE SECTION..(O/S/Q)
 NOTE THAT FOR VERTICAL DATABASE OUTPUT USE S, BEFORE Q

 DO YOU WANT HORIZONTAL NOISE ROSES (Y/N)?

 WHAT FREQUENCIES FOR PLOTTING , 10-10KHZ ?
 INPUT 6 VALUES, NEAREST 1/3 OCTAVES USED, 0 OK
?
50 500 0 0 0 0
 FREQUENCY (HZ), REQUESTED (HZ)
  50.0000000        50.0000000
 WIND SPEED (KN)
  15.0000000
 HORIZONTAL NOISE SOURCES DB//UPA**2/(HZ-DEG)
 ITS SECTOR BEARING(DEG) AND WIDTH(DEG)
 NORTH AND SOUTH HILAT NOISE
  49.3794159       0.000000000E+00     9.06700862
  57.2236938       180.000000          55.2389832
 NORTH, SOUTH, EAST, WEST + BASIN
  43.5114136       0.000000000E+00     90.0000000
  43.5114136       180.000000          90.0000000
  50.0776367       90.0000000          90.0000000
  50.0776367       270.000000          90.0000000
 WIND LANES
  41.7400818       270.000000          78.7160034
 SHIP LANES
  74.9943848       73.0000000          1.00000000
  50.1631927       270.000000          68.2442932
 LIST OF HORIZONTAL NOISE LEVELS AND THEIR ANGLES
       N ,  DEGREES, DB//UPA**2/(HZ-DEG)
         1  0.000000000E+00     50.8628556
         2   4.53364931         43.5114136
         3   45.0000000         50.0776367
         4   72.5000000         75.0083008
         5   73.5000000         50.0776367
         6   135.000000         43.5114136
         7   152.380508         57.4046021
         8   180.000000         57.4046021
         9   207.619492         43.5114136
        10   225.000000         50.0776367
        11   230.641998         50.6719055
        12   235.877853         53.4353027
        13   304.122070         50.6719065
        14   309.367910         50.0776367
        15   315.000000         43.5114136
        16   355.466300         50.8628556
 OMNIDIRECTIONAL NOISE DB//UPA**2/HZ
  79.6499176       15.0000000       KNOTS
```

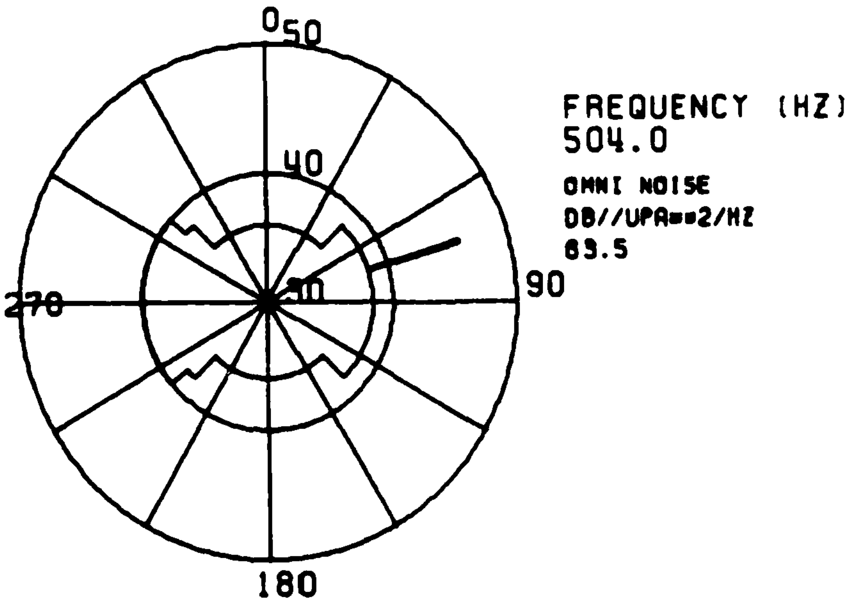


I.9 Horizontal directionality(Contd.).

```
C
 FREQUENCY (HZ), REQUESTED (HZ)
  504.000000        500.000000
 WIND SPEED (KN)
  15.0000000
 HORIZONTAL NOISE SOURCES DB//UPA**2/(HZ-DEG)
 ITS SECTOR BEARING(DEG) AND WIDTH(DEG)
 NORTH AND SOUTH HILAT NOISE
 -9.57468128       0.000000000E+00    9.06709862
 -10.2733612       180.000000         55.2389832
 NORTH, SOUTH, EAST, WEST + BASIN
  35.9886627       0.000000000E+00    90.0000000
  35.9886627       180.000000         90.0000000
  38.3612518       90.0000000         90.0000000
  38.3612518       270.000000         90.0000000
 WIND LANES
  35.1770172       270.000000         78.7160034
 SHIP LANES
  45.2255554       73.0000000         1.00000000
  16.5969849       270.000000         68.2442932
 LIST OF HORIZONTAL NOISE LEVELS AND THEIR ANGLES
       N ,   DEGREES, DB//UPA**2/(HZ-DEG)
          1  0.000000000E+00      35.9887848
          2   4.53364831          35.9886627
          3   45.0000000          38.3612518
          4   72.5000000          46.0385284
          5   73.5000000          38.3612518
          6   135.000000          35.9886627
          7   152.380508          35.9887606
          8   180.000000          35.9887606
          9   207.619492          35.9886627
         10   225.000000          38.3612518
         11   230.641900          40.0640667
         12   235.877853          40.0644574
         13   304.122070          40.0640667
         14   309.357910          38.3612518
         15   315.000000          35.9886627
         16   355.466309          35.9887848
 OMNIDIRECTIONAL NOISE DB//UPA**2/HZ
  63.5114288       15.0000000         KNOTS
```

01/11/88 NOISE ROSE

DUNES (2.3) WIND SPEED = 15.0 KN LEVELS DB//UPA**2/(HZ-DEG)



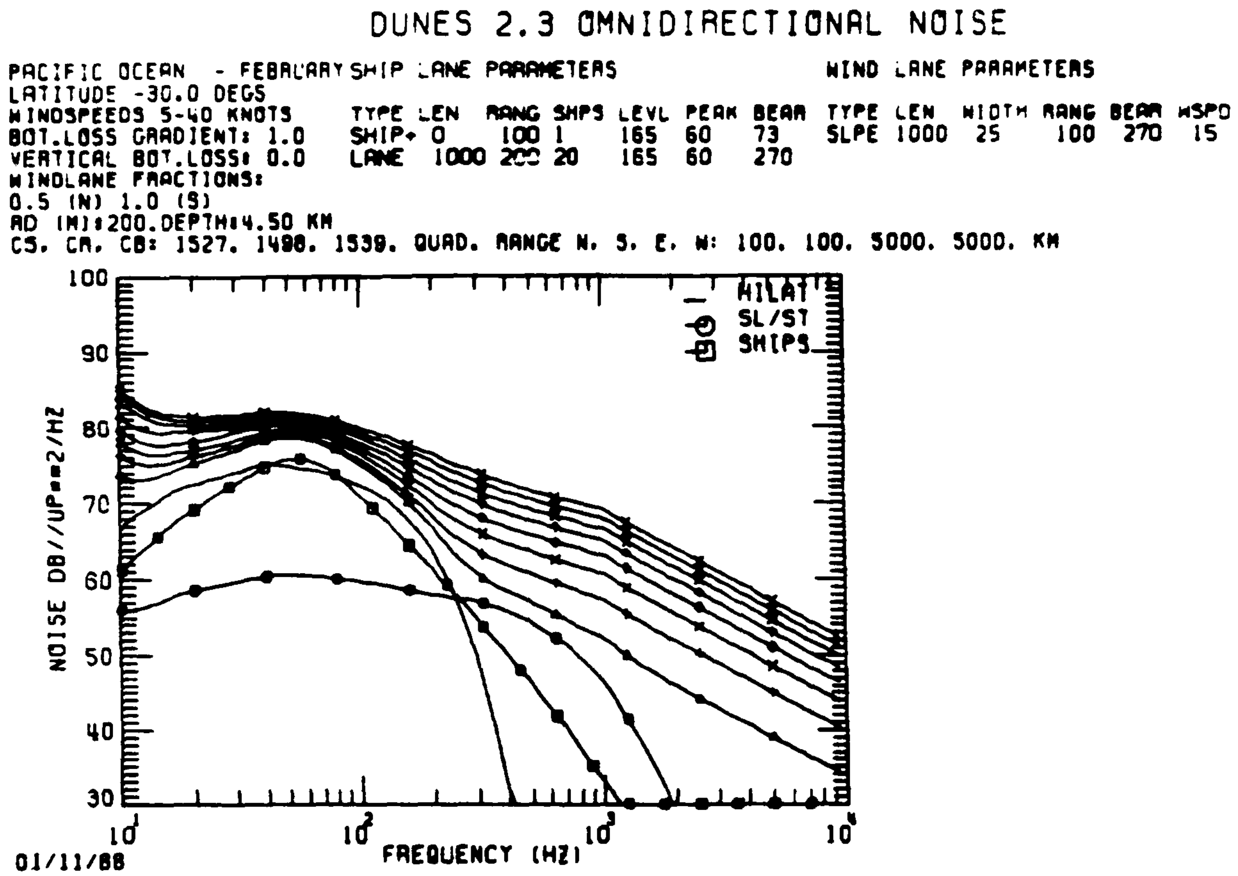
I.10 Output to database files

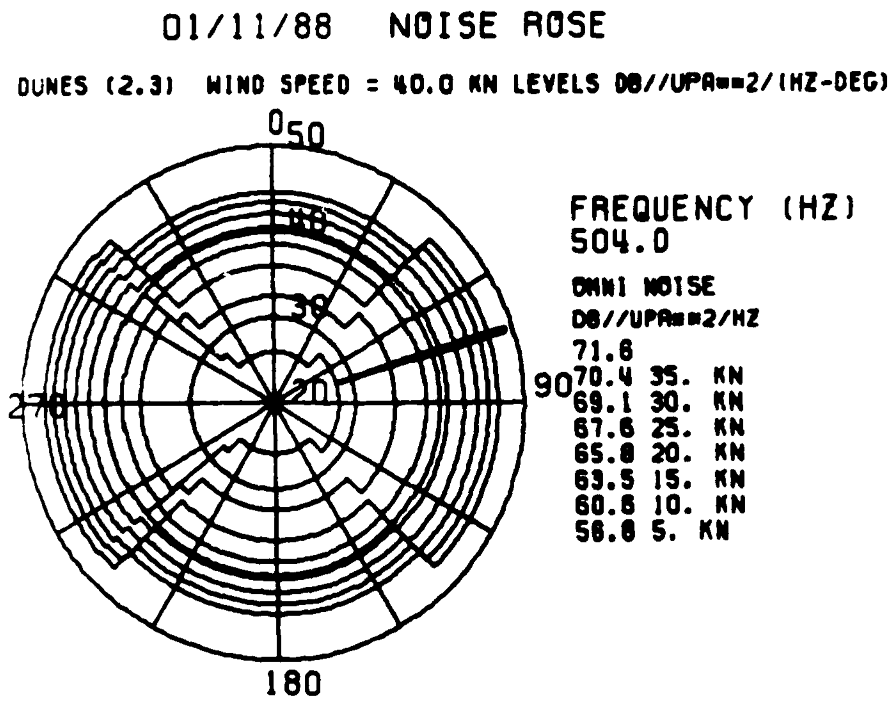
```
DO YOU WANT TO FILE IN DATA BASES? (Y/N)
REMEMBER ONLY THE WIND SPEEDS REQUESTED WILL BE OUTPUT
Y
 UNIT 8 = VERTICAL, UNIT 9 = OMNI, UNIT 10 = HORIZ,  UNIT 11 = 3D
WHICH FILES ? EG VOH3 (FOR ALL), VO (FOR ONLY 2) VOH3
  FREQ,VERT DIRECTIONAL NOISE DB//UPA**2/HZ-SR
   20.0000000                  1   57.5717621
   20.0000000                  2   57.5717621
   20.0000000                  3   63.5368958
   20.0000000                  4   63.5368958
   20.0000000                  5   74.9880981
   20.0000000                  6   74.9880981
   20.0000000                  7   70.5552826
   20.0000000                  8   70.5552826
   20.0000000                  9   74.9880981
   20.0000000                 10   74.9880981
   20.0000000                 11   63.5427246
   20.0000000                 12   63.5427246
   20.0000000                 13   58.4797974
   20.0000000                 14   58.4797974
   15.0000000        20.0000000       77.2177429
  FREQ,VERT DIRECTIONAL NOISE DB//UPA**2/HZ-SR
   26.0000000                  1   57.4681854
   26.0000000                  2   57.4681854
   26.0000000                  3   63.9388885
   26.0000000                  4   63.9388885
   26.0000000                  5   74.9998169
   26.0000000                  6   74.9998169
   26.0000000                  7   71.6599731
   26.0000000                  8   71.6599731
   26.0000000                  9   74.9998169
   26.0000000                 10   74.9998169
   26.0000000                 11   63.9466858
   26.0000000                 12   63.9466858
   26.0000000                 13   58.3763885
   26.0000000                 14   58.3763885
   15.0000000        26.0000000       77.8751373
  FREQ,VERT DIRECTIONAL NOISE DB//UPA**2/HZ-SR
   32.0000000                  1   57.4230194
   32.0000000                  2   57.4230194
   32.0000000                  3   64.5105896
   32.0000000                  4   64.5105896
   32.0000000                  5   75.1233368
   32.0000000                  6   75.1233368
   32.0000000                  7   72.7567749
   32.0000000                  8   72.7567749
   32.0000000                  9   75.1233368
   32.0000000                 10   75.1233368
   32.0000000                 11   64.5207367
   32.0000000                 12   64.5207367
   32.0000000                 13   58.3327484
   32.0000000                 14   58.3327484
   15.0000000        32.0000000       78.6315155
  FREQ,VERT DIRECTIONAL NOISE DB//UPA**2/HZ-SR
   40.0000000                  1   56.4258270
   40.0000000                  2   56.4258270
   40.0000000                  3   65.3389740
   40.0000000                  4   65.3389740
   40.0000000                  5   75.4037170
```

) Vertical noise levels
) at 14 angles provided
) for checking 3D option
) data

List continues for all frequencies chosen by DUNES - see vertical noise values

I.11 Alternative output options - all wind speeds





APPENDIX II

DUNES 2.3 RUNS - INPUT WORKSHEET

COMMENTS: TEST

DATE :
FILE :
GDBMS ADDRESS :

OCEAN: Pacific [√] Indian [____] Atlantic [____]

RECEIVER LATITUDE: -30 LONGITUDE: ________ (not used)
RECEIVER DEPTH (M): 200
SEASON: February [√] August [________]
SOUND SPEEDS (M/S): Default [_____] or CS 1527 CR 1498 CB 1539
BOTTOM DEPTH (KM): 4.5
CLEAR RANGE OF TRANSMISSION BLOCKAGE IN 4 QUADRANTS (+- 45 DEG):
N 0.1 S 0.1 E 5 W 5
LOW ANGLE BOTTOM LOSS SLOPE FACTOR 1 (1.0 = average)
HIGH ANGLE BOTTOM LOSS DB SHIFT 0 (0 dB = average)
ANGLE LIMIT LOC NOISE ______ (Deg) or CSUBB ______ (M/S) or Default [√]
HIGH LATITUDE WIND NOISE FRACTIONS N 0.5 S 1
AND THEIR BEARINGS (DEG) N 0 S 180 (usually 0,180)

WIND LANES 1

#	ENHANCED (Y=SLOPE,N=STORM)	LENGTH (KM)	WIDTH (KM)	RANGE (KM)	BEARING (DEG) RE R	WINDSPEED (KN)
1	Y	1000	25	100	270	15
2						
3						
4						
5						

SHIP CONTRIBUTIONS ________

#	ENHANCED (Y/N)	LENGTH (KM)	RANGE (KM)	BEARING (DEG) RE R	# SHIPS	PEAK-LVL (DB)	FREQ (HZ)
1	Y	0	100	73	1	165	60
2	N	1000	200	270	20	165	60
3							
4							
5							

SELECTED WIND SPEED 15 DATA OUTPUT FOR DATABASES Y (Y/N)
WHICH OF V O H 3 ? VOH3

DUNES 2.3 RUNS - INPUT WORKSHEET

COMMENTS:

DATE :
FILE :
GDBMS ADDRESS :

OCEAN: Pacific [____] Indian [____] Atlantic [____]

RECEIVER LATITUDE: ________ LONGITUDE: ________ (not used)
RECEIVER DEPTH (M): ________
SEASON: February [________] August [________]
SOUND SPEEDS (M/S): Default [_____] or CS _____ CR _____ CB _____
BOTTOM DEPTH (KM): ________
CLEAR RANGE OF TRANSMISSION BLOCKAGE IN 4 QUADRANTS (+- 45 DEG):
N _____ S _____ E _____ W _____
LOW ANGLE BOTTOM LOSS SLOPE FACTOR ________ (1.0 = average)
HIGH ANGLE BOTTOM LOSS DB SHIFT ________ (0 dB = average)
ANGLE LIMIT LOC NOISE ______ (Deg) or CSUBB ______ (M/S) or Default [______]
HIGH LATITUDE WIND NOISE FRACTIONS N ______ S ______
AND THEIR BEARINGS (DEG) N ______ S ______ (usually 0,180)

WIND LANES ________

#	ENHANCED (Y=SLOPE,N=STORM)	LENGTH (KM)	WIDTH (KM)	RANGE (KM)	BEARING (DEG) RE R	WINDSPEED (KN)
1						
2						
3						
4						
5						

SHIP CONTRIBUTIONS ________

#	ENHANCED (Y/N)	LENGTH (KM)	RANGE (KM)	BEARING (DEG) RE R	# SHIPS	PEAK-LVL (DB)	FREQ (HZ)
1							
2							
3							
4							
5							

SELECTED WIND SPEED _____ DATA OUTPUT FOR DATABASES _____ (Y/N)
WHICH OF V O H 3 ? _____

APPENDIX III

BOTTOM LOSS DATA FOR DUNES 2.3

Finding the data values to use from the measured or theoretical bottom loss versus grazing angle curve.

```
Bottom    |
Loss      |
(dB)      |       ************************************** = β = 10 log b
          |       *
          |       *
          |       *
          |      **
          |     * *
          |    *  *
          |   *   *
          |  *    *
          | *     *
          ---------------------------------------------------------
          0      θ                                       90
                  c
                     θ (Grazing angle (degrees))
```

Below θ_c the curve is approximated by $a_s\ \theta$ where a_s is decibels/radian. Above θ_c the curve is a constant β.

III.1 Input data requires S, where a_s = S * 3 f**1.5 dB/rad.

Default is S = 1.0 For a high slope use S > 1.
For a low slope use S < 1.

III.2 Input data requires β_2, where $\beta = \beta_1 + \beta_2$ (dB)

and $\beta_1 = 2.9 + 2 \sin(3.5 \log f - 6.82)$

$= 0.9 < 32$ Hz
$= 3.88 > 500$ Hz

Default is $\beta_2 = 0$ (dB) For high loss use $\beta_2 > 0$
For low loss use $\beta_2 < 0$

with $\beta >= 0.5$ dB always

III.3 Input data requires θ_c, the breakpoint from slope to constant value. It is found by either

(i) θ_c specified, suggested values are the angle with bottom loss -3 dB down from the 90° value or angle of intromission when $C_o/C_{bb} > 1$

(ii) $\cos^{-1} (C_o/C_{bb})$, C_{bb} = sound speed in bottom sediment

(iii) default $\cos^{-1} (C_o/1.1{*}C_b)$, C_b = sound speed at bottom C_o is water sound speed at receiver.

APPENDIX IV

NOTES ON IBM PC USEAGE

Graphics requires the equivalent of the Color Graphics Adapter and a graphics monitor. More capable cards and monitors will have the minimum requirement of two colours on a 640 by 200 resolution screen.

Graphics dump of the screen goes to the standard IBM PC printer, Epson or similar type. Be sure to use the GRAPHICs command before running DUNES for the first time. Add it to your AUTOEXE.BAT.

Each subroutine is compiled using MS-FORTRAN 3 and above versions. Some subroutines are lumped together in the same *.FOR so there is no need to refer to everyone of them.

LINK to GRAFX+8087+FORTRAN using the @ option for the OBJs and use either DLINK.PLT or DLINK.NPL for plots or no plots, respectively.

To run type in

DUNES,CON,TEST1.DAT

to use the data file TEST1.DAT and replies go to the terminal CON.

DUNES,CON,CON

will run with data prompts to be typed in as you go.

The DUNES.EXE has been compressed by using the MS supplied program EXEPACK.EXE. This reduced the storage from 172K to 122K.

The 8087 coprocessor is required.

Output to database files will generate requests for file names for UNIT numbers 8 to 11. Give answer as CON or TEST1.OMN,TEST1.VER accordingly.

APPENDIX V

SOURCE LEVEL UNITS

For source levels referenced to steradians it is easy to show that these values approximately correspond to the effective source level that would be received 1 m from an area 1 m by 1 m. First we examine two cases.

(1) The vertical angle subtended by a circular plane area of 1 m^2 at a point 1 m away is 58.86° (or 29.43° half angle). This corresponds to a solid angle of 0.811 sr. The ratio of the plane area to the area on a sphere centred at the apex of the angle is 1:1.0690 or -0.29 dB re 1 sr.

(2) The area on a sphere of radius 1 m centred at the apex by the angle of 1 sr is 1 m^2. The vertical angle subtended is 65.54 (or 32.77° half angle). This arrangement corresponds to a circular area which is 0.84 m away. The ratio of the plane area to the area on a sphere subtended by 1 sr is 0.9204:1 or -0.36 dB re 1 sr.

These two cases bound an estimated -0.3 dB error when equating the two definitions of source level. This value could be subtracted from equation (1).

The vertical linear arrays used to measure the vertical noise levels had a higher end fire resolution than 60° due to more than 7 hydrophones or adaptive beamforming. Therefore the influence of the source directionality over the range of angles between ± 60° and ± 90° can be shown to be even smaller in determining the source level.

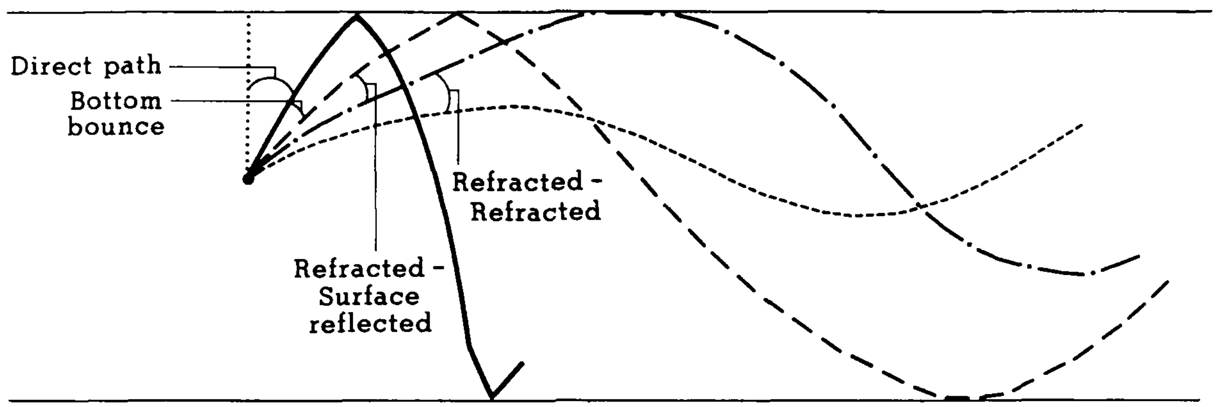


Figure 1. Transmission types to receiver at R

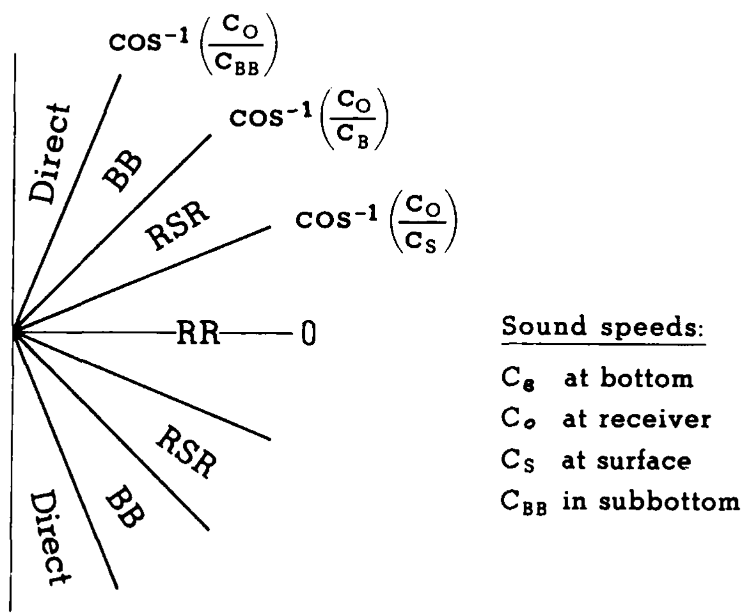


Figure 2. Vertical angle assignments for transmission types

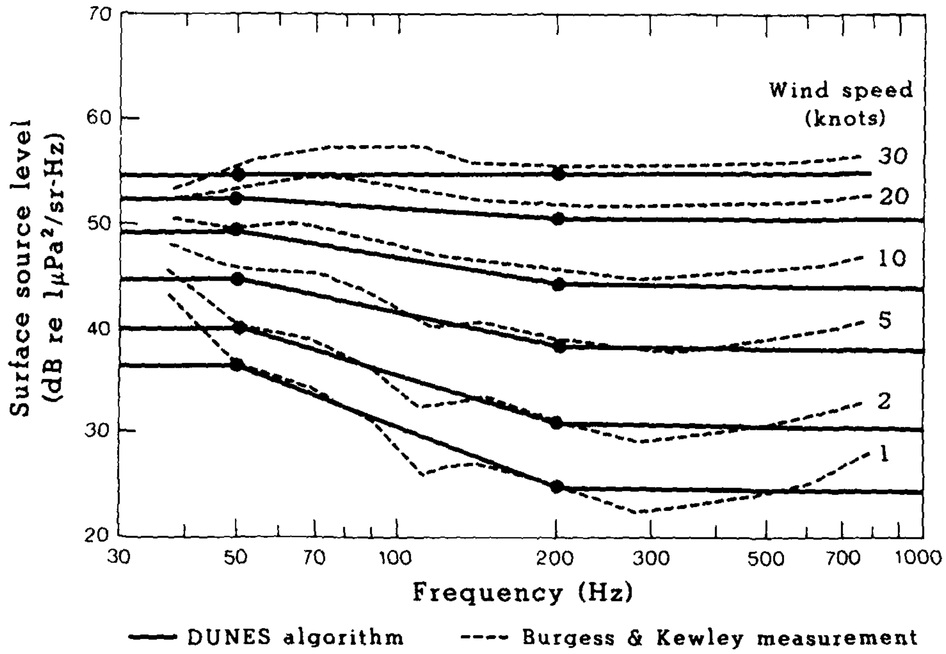


Figure 3(a). Surface source level of wind generated noise ____ DUNES algorithm, - - - Burgess and Kewley measurement

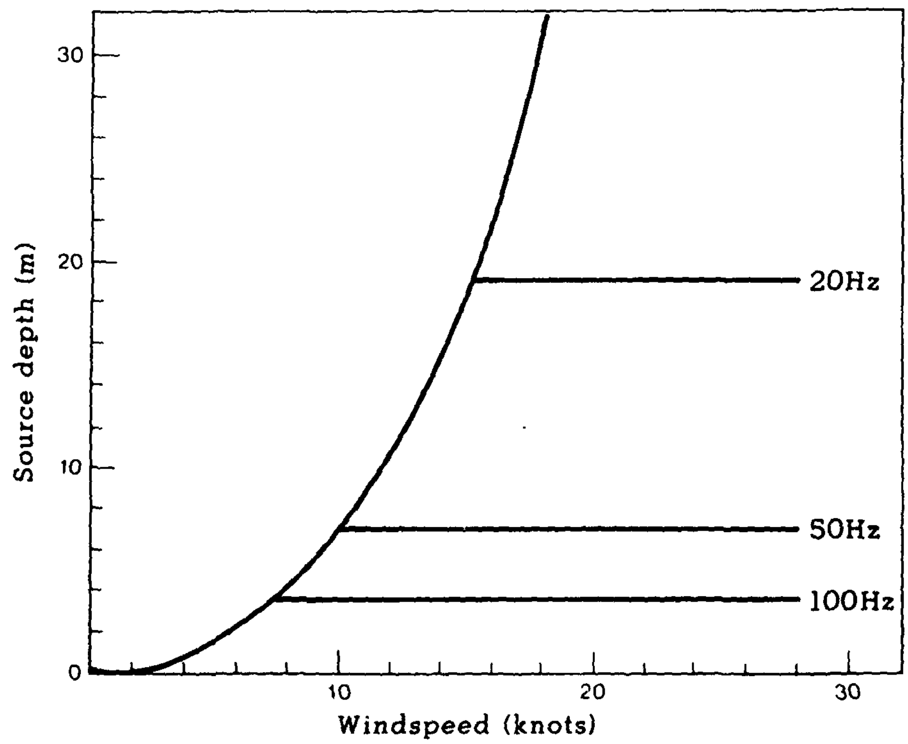


Figure 3(b). Variation of source depth (m) with wind speed and frequency

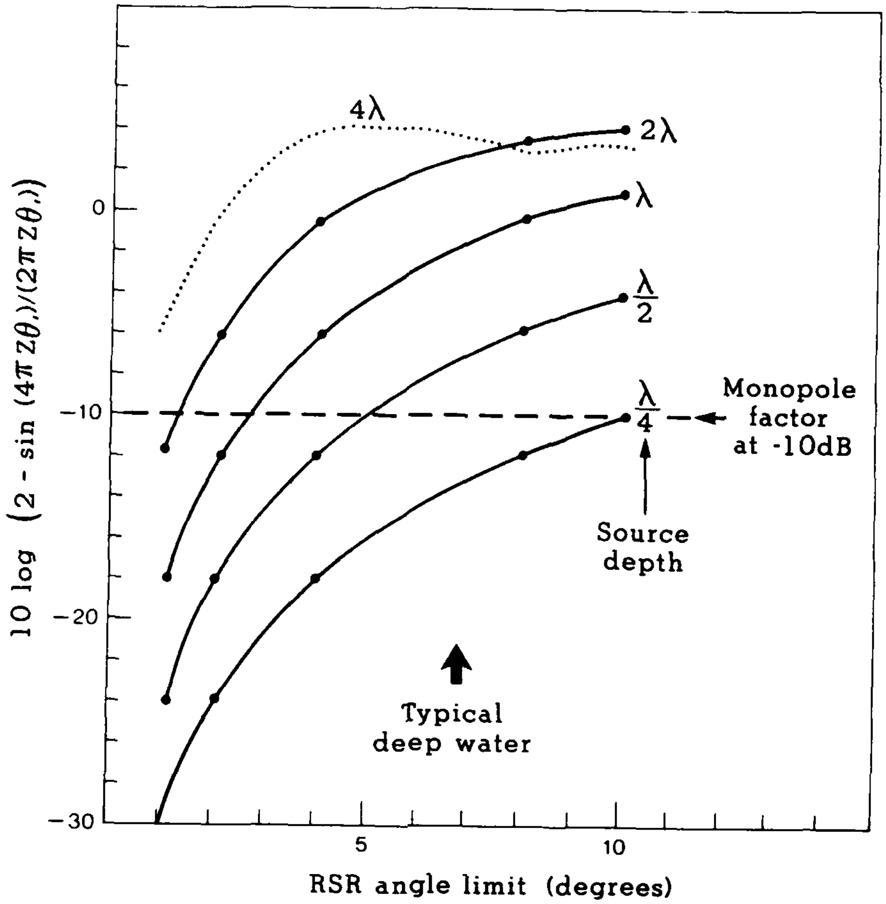


Figure 4. Dipole source decoupling factor versus angle

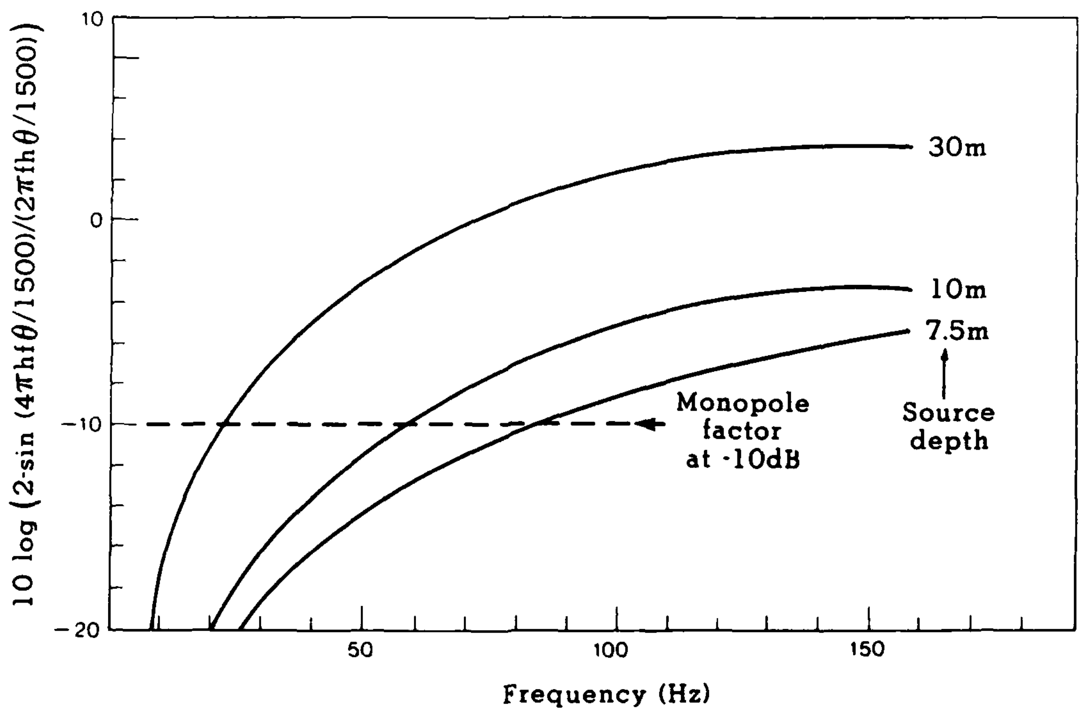


Figure 5. Dipole source decoupling factor versus frequency

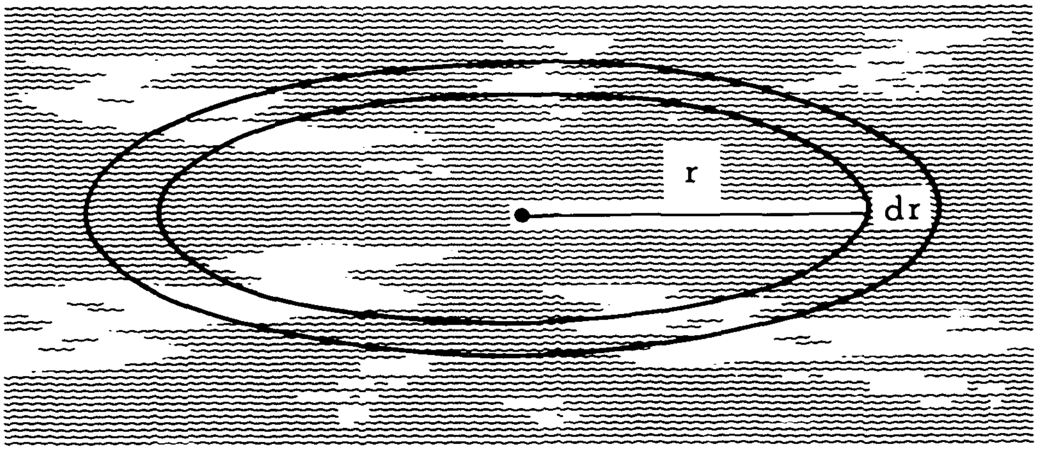


Figure 6. Annulus of the ocean surface used to integrate surface noise levels

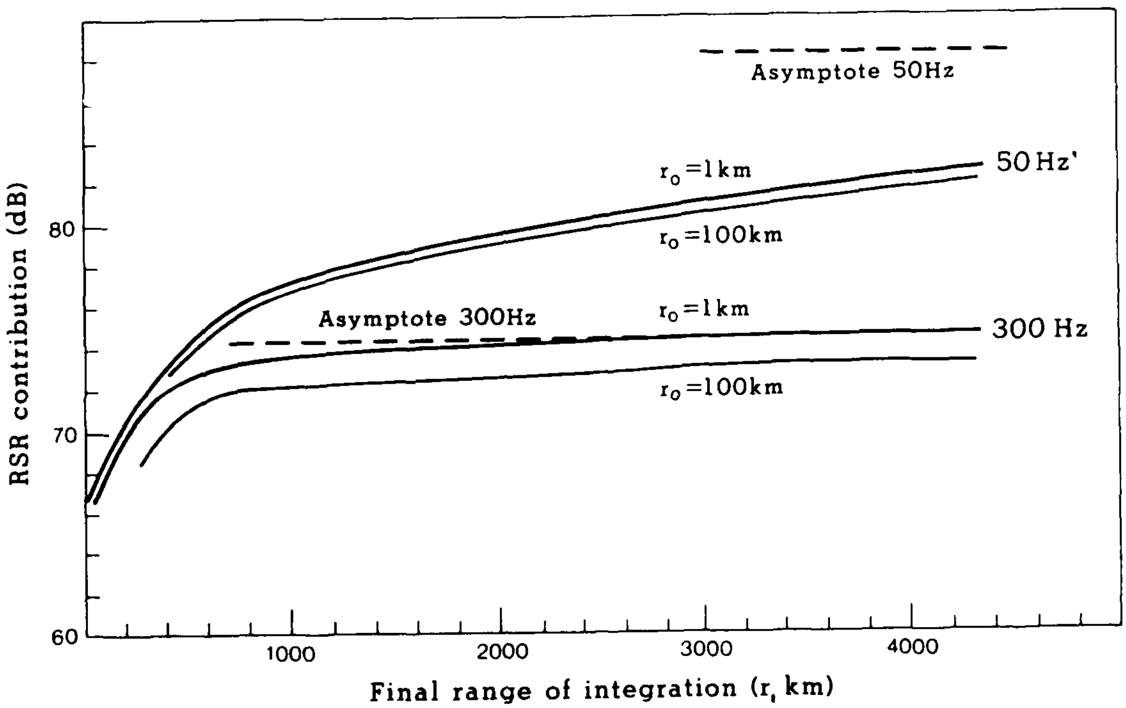


Figure 7. The RSR noise contribution under 10 kn wind conditions without dipole correction

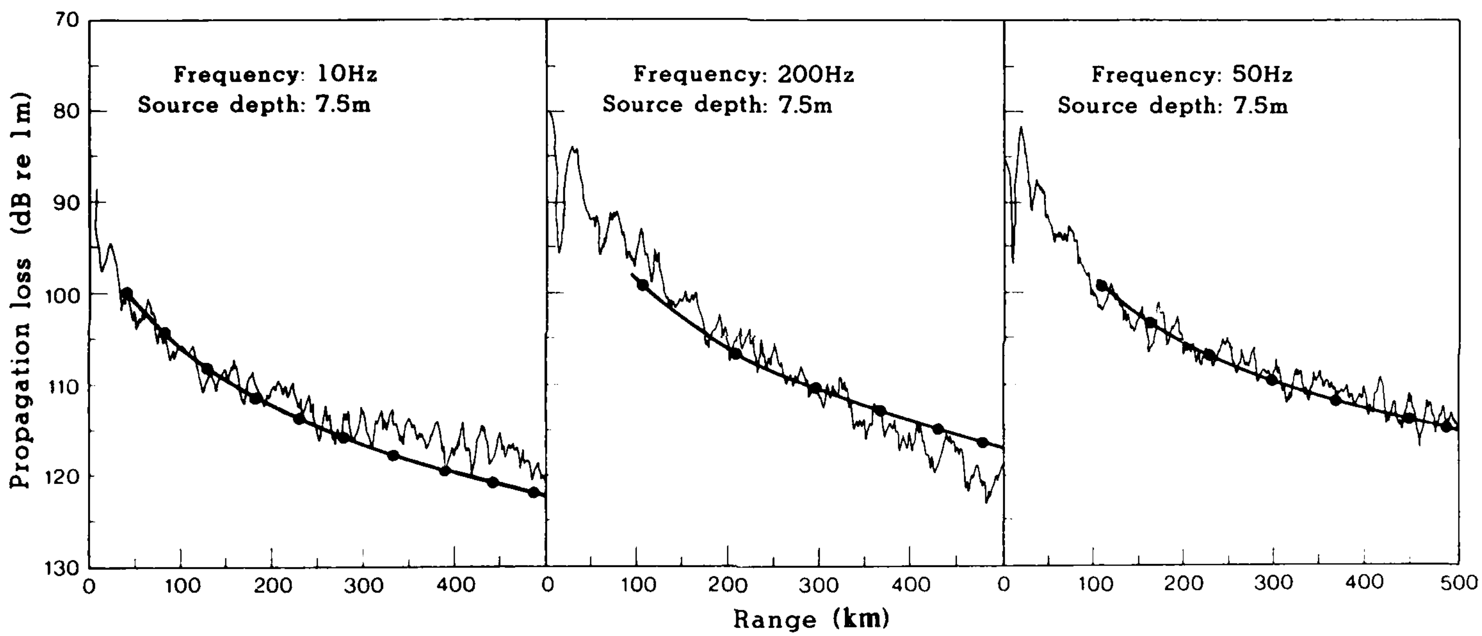


Figure 8. Comparison between simple model ●-● and PE _ _ _ for case of 7.5 m source depth with bottom bounce condition

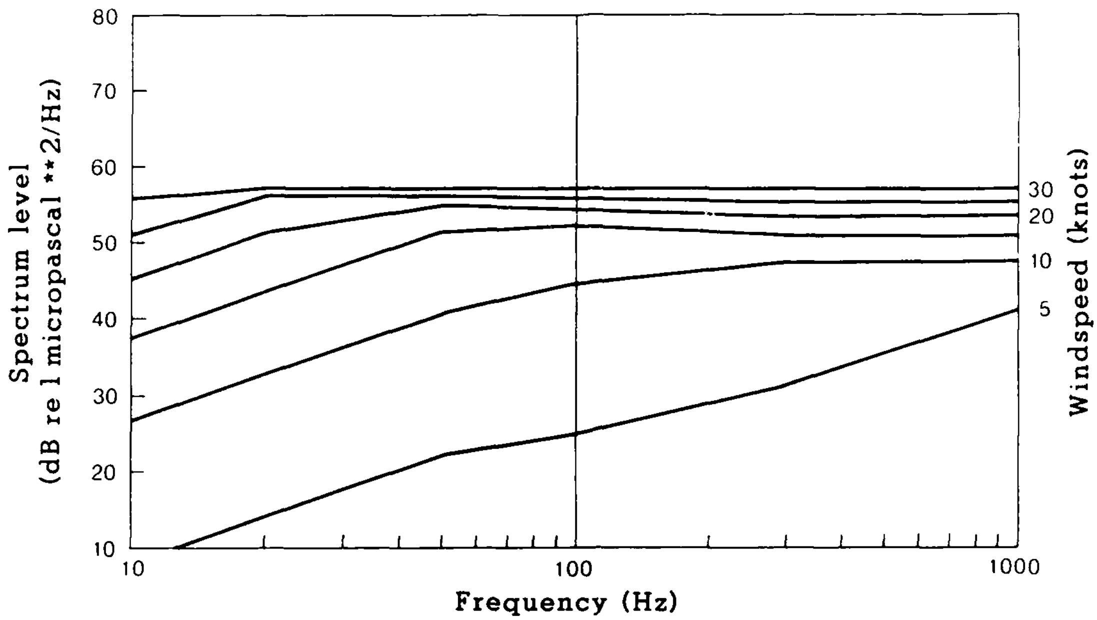


Figure 9(a). The magnitude of the extra downward component at various wind speeds

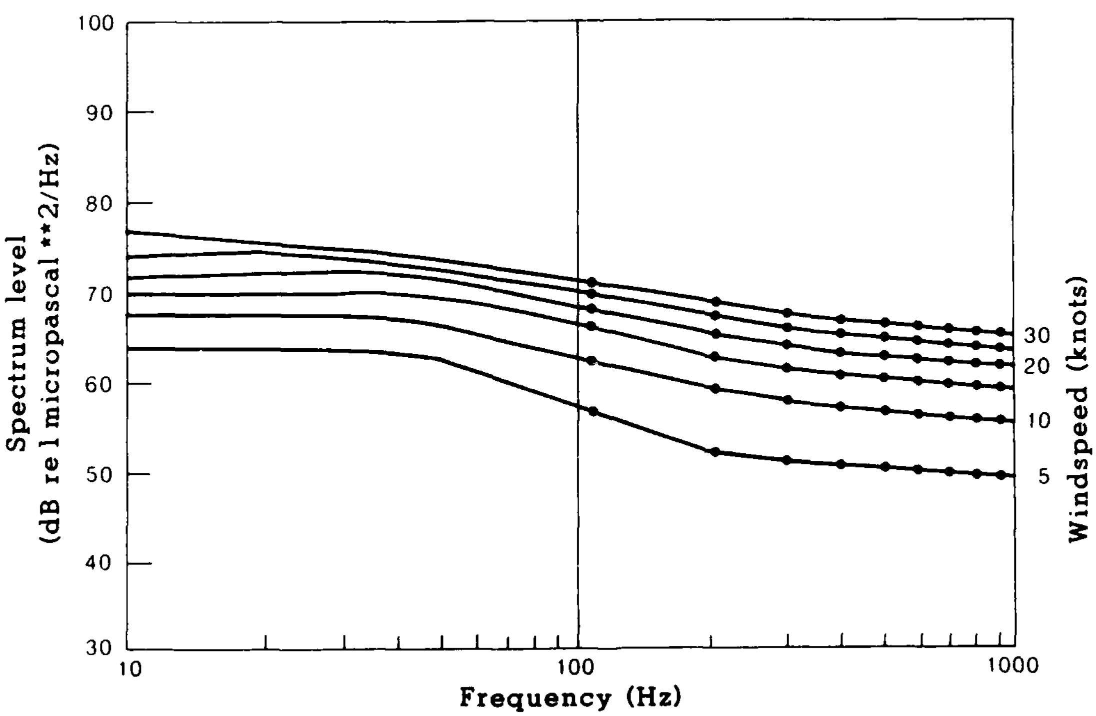


Figure 9(b). The magnitude of the bottom bounce component at various wind speeds

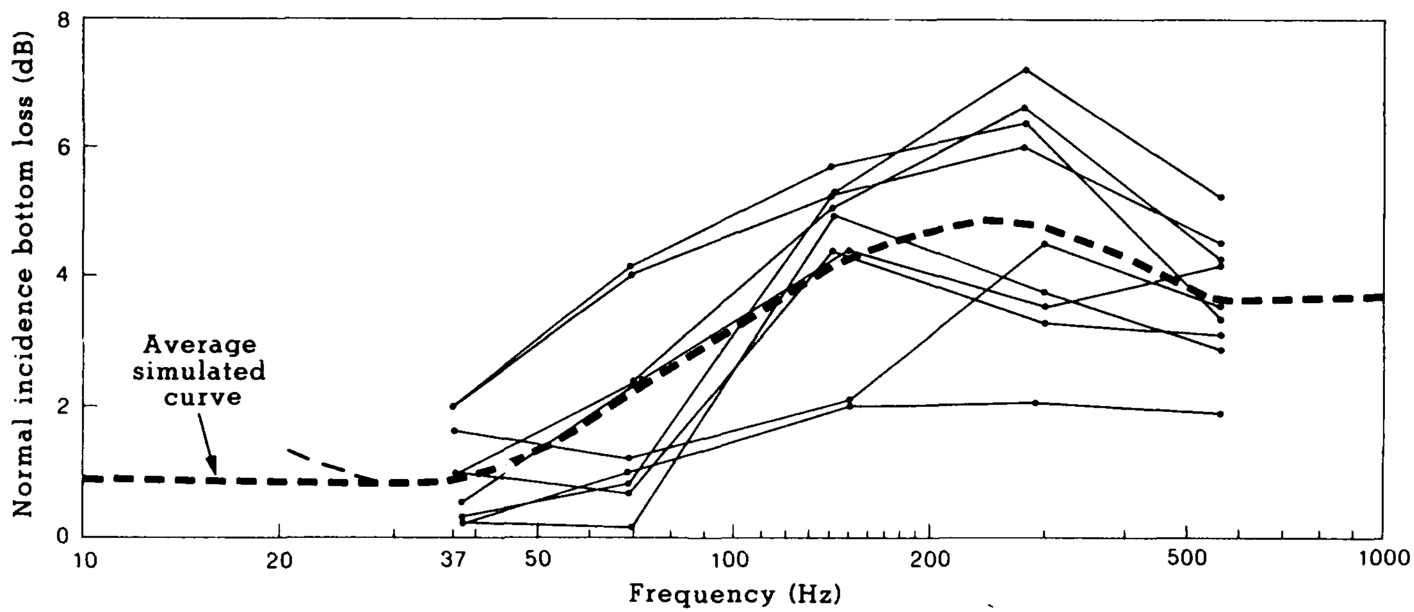
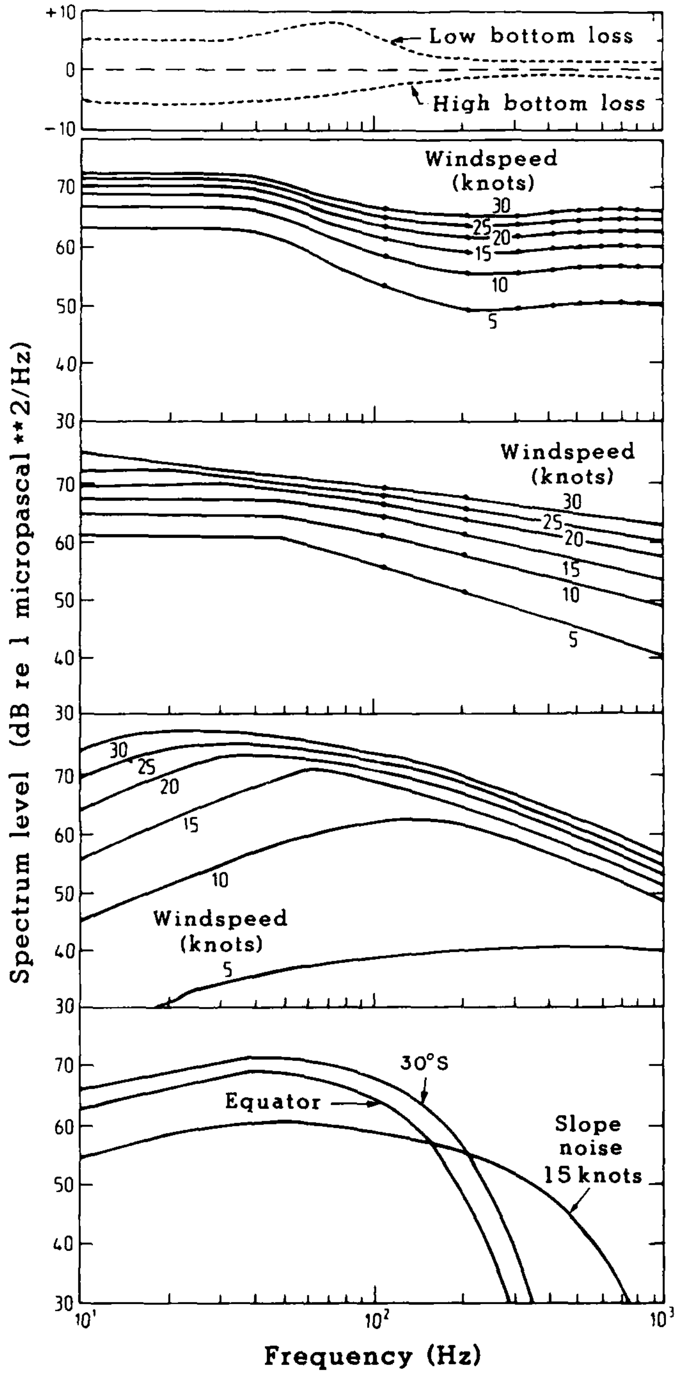


Figure 10. Normal incidence bottom loss as function of frequency simulated



DIRECT PATH COMPONENT (30°- 90°)

Adjust for bottom loss by adding top panel correction

BOTTOM BOUNCE COMPONENT (12°- 30°)

Adjust for waterdepth H(m) and bottom loss scalar (L) by adding:

$$10 \log \left(\frac{H}{5000} \cdot L\right)$$

RSR COMPONENT (10°- 12°)

Adjust for depth excess D(m) by adding:

$$10 \log (D/1000)$$

RR COMPONENT ($\pm 10°$)

Adjust for slope windspeed W(kt) and range R(km) by adding:

$$10 \log \left(\left(\frac{W}{15}\right)^3 \cdot \frac{R}{100}\right)$$

Figure 11. Generalised wind noise spectra

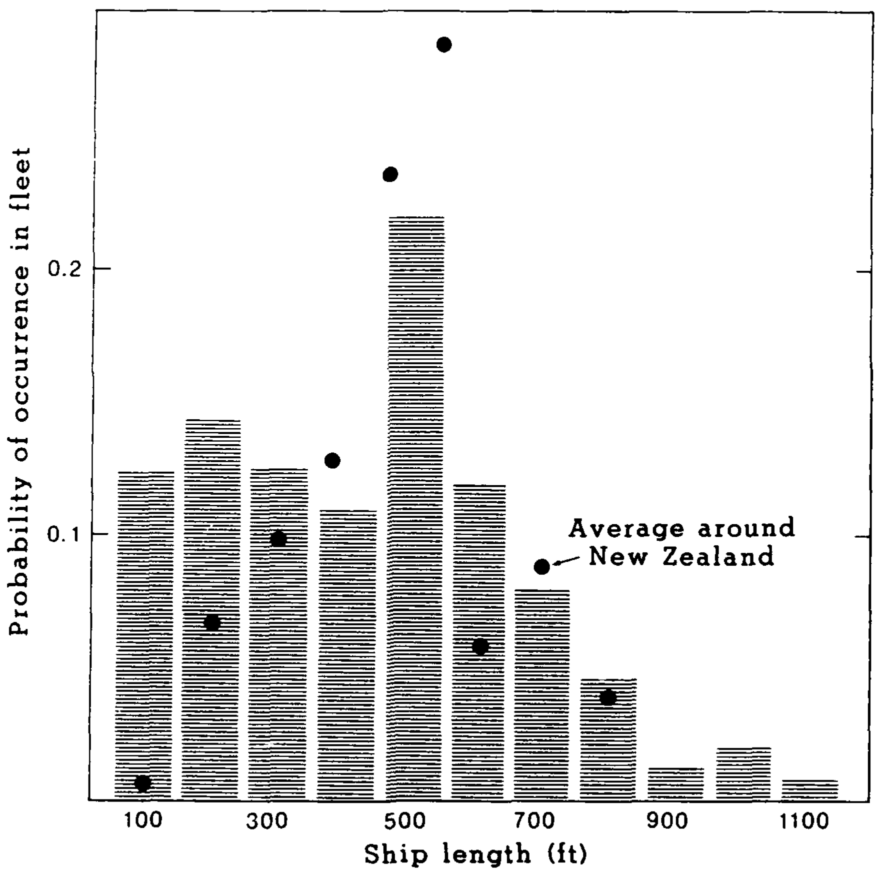


Figure 12. Distribution of ship length for world fleet and for New Zealand(ref.26,28)

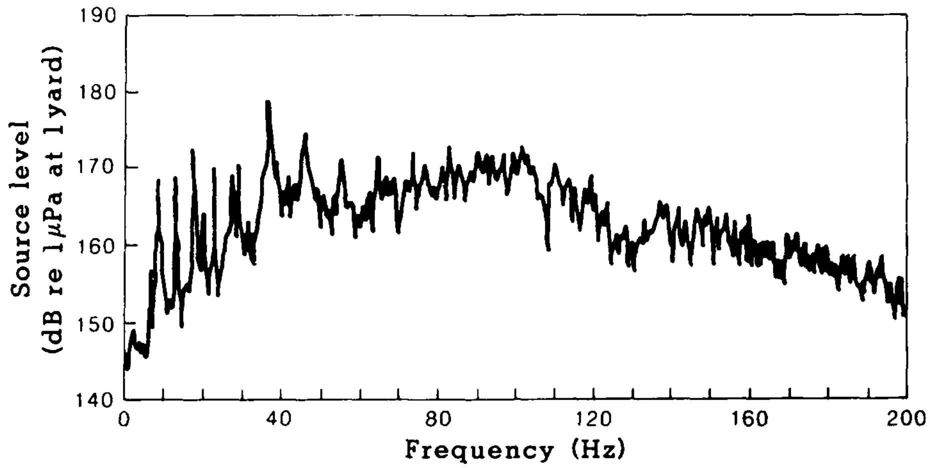


Figure 13(a). Source power spectrum level of a 600 ft bulk carrier measured at a depression angle of 20°

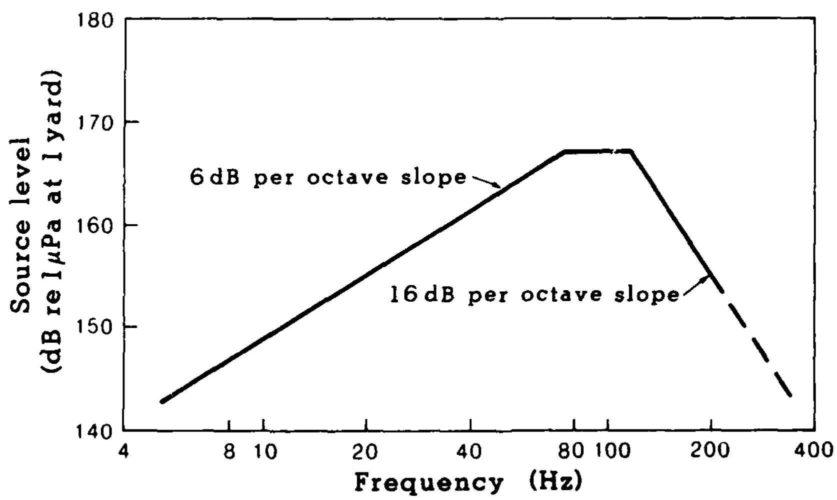


Figure 13(b). Envelope of continuous radiation from a bulk carrier observed at a 29° depression angle

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17 SUMMARY OR ABSTRACT
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The modelling of the directionality of underwater noise due to wind-generated noise sources and shipping is presented. The formulations are incorporated in the Directional Underwater Noise Estimates (DUNES) model. It provides estimates of omnidirectional, vertical, horizontal and three dimensional directional noise versus frequency. The model includes features hitherto unknown in models of this type, ie. high latitude and coastal slope enhanced wind noise. The model emphasises the calculation of noise due to the natural environment and therefore shipping contributions have to be entered explicitly, unlike some other models which incorporate extensive shipping databases. Long range wind noise is considered to be described by storms over a finite area and bearing or along continental shelves. Shipping is described by individual ships or shipping lanes over continental shelves or deep ocean. The model has been used on a range of computers such as the IBM PC, VAX 11/750 and IBM 3033. Examples of use for Version 2.3 are provided.

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